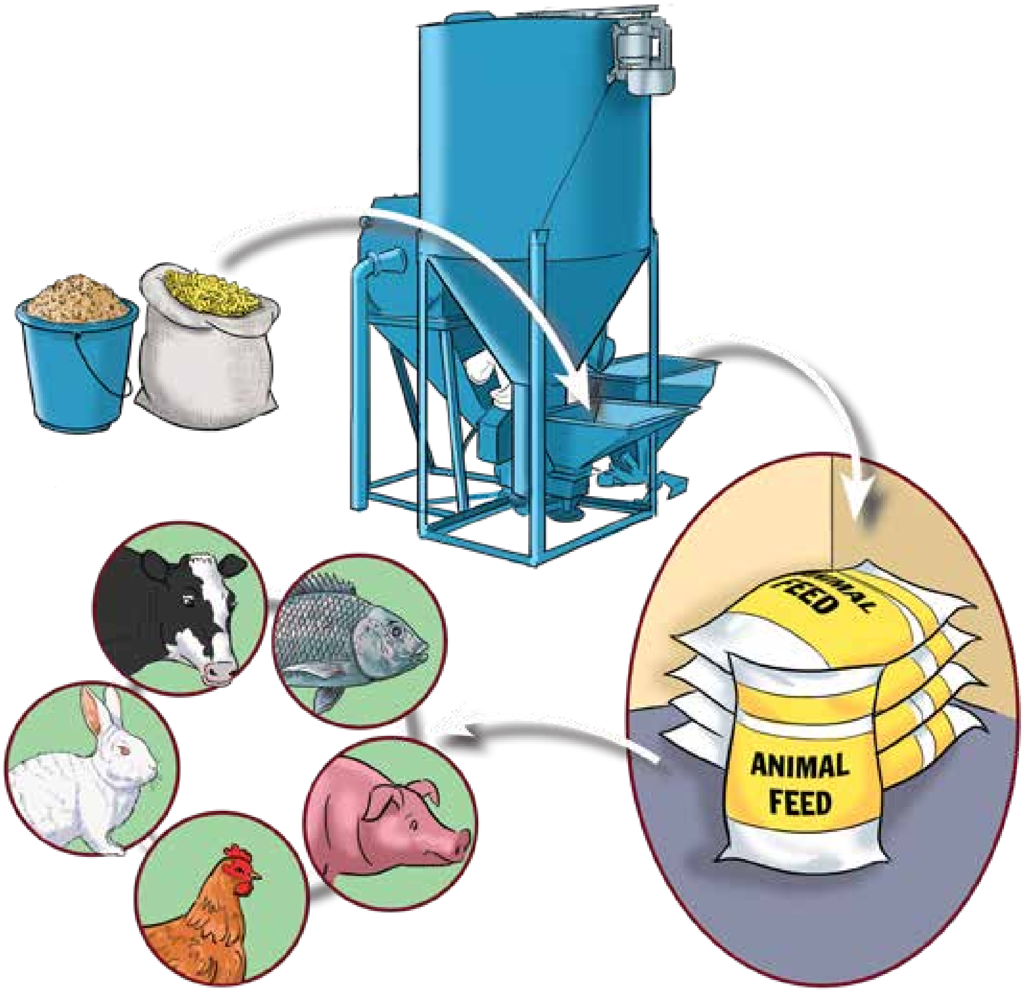

ILRI MANUAL

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RESEARCH PROGRAM ON Livestock
CGIAR

Feed formulation and mixing for small-scale feed producers

Feed formulation and mixing for small-scale feed producers

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International Livestock Research Institute (ILRI)

June 2021

ILRI thanks all donors and organizations which globally support its work through their contributions to the CGIAR Trust Fund

Editing, design and layout—ILRI Editorial and Publishing Services, Addis Ababa, Ethiopia.

Cover illustration— ILRI/Simon Ndonye

ISBN: 92–9146–657–4

Citation: Gachuiri, C. and Lukuyu, B. 2021. *Feed formulation and mixing for small-scale feed producers*. ILRI Manual 45. Nairobi, Kenya: ILRI.

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Acknowledgements

The authors would like to acknowledge the following persons for their assistance and contributions during the preparation of the manual.

The authors would like thank the workshop participants who discussed the needs of small-scale feed producers and contributed to the development of the course content for this manual. The participants include Pius Lutakome of the International Livestock Research Institute (ILRI), Fred Kabi and Denis Asizua from Makerere University (MAK), Wonekha N. Deogracius of the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), Salome Lukwiya Angom from the Network of Ugandan Research and Research Users (NURRU), Andrew A. Mwebaze of the National Livestock Resources Research Institute (NaLIRRI), George William Byamukama of Professional Associates Limited (PAL) and Ssenyonga Hakimu, a representative of the small-scale feed millers.

The authors would also like to thank Simon Ndonye who drew the illustrations used in this manual to ensure clarity.

This manual was produced by ILRI as part of the More Pork Project Phase II 'Improving pig productivity, incomes, and pork safety through an environmentally sustainable and gender inclusive integrated intervention package' and funded by the CGIAR Research Program on Livestock https://www.ilri.org/research/ilri-cgiar-programs/livestock

Preamble

Animal productivity is affected by several factors, both within and outside the animal. The key factors are the animal's potential (determined by genetics), nutrition (both quality and quantity), environmental factors (e.g. weather) and managerial factors (e.g. health, comfort). Genetic improvement is typically a one-off investment, while external factors are more difficult to control. Feeding is a daily activity and is subject to more variation. Feeding constitutes 50–70% of production costs for domestic animals, being higher in non-ruminants that consume foodstuffs in competition with humans.

In developing countries, many studies have documented that the major constraint on livestock production is the availability and quality of feeds. The intensification of animal production in developing countries, coupled with improved genetics, requires feed to be of sufficient quantity and quality to exploit the full potential of these animals. For ruminant livestock, forage feeding alone may not suffice, and a supplementation using commercial concentrates may be required. Intensive non-ruminant production is fully dependent on commercial concentrates.

Due to the high cost of commercial concentrates in most developing countries (attributed to competition with humans for cereals), livestock keepers demand that these feeds be of a requisite quality. Complaints of feed available in the market of insufficient quality leading to losses by farmers have been documented. The quality of these commercial feeds is governed by standards which are set by respective standards bodies in each country within the east African region. However, enforcement of these standards has been difficult due to resource constraints within the enforcement agencies.

As livestock production becomes more intensive, compounded feed producers will play a bigger role in overall livestock productivity, as an intensification of livestock production is accompanied by a higher reliance on commercial concentrates. Feed producers must be conscious of the key role they play and endeavour only to produce quality assured feeds.

While there are large-scale feed manufacturers within the East African region, there has been a recent increase of both medium- and small-scale feed manufacturing enterprises. This has led to difficulties in enforcing quality standards, as these entrepreneurs often have only a minimal understanding and knowledge of what is required of quality animal feeds.

This manual aims to simplify the science of feed manufacturing to enable start-ups to meet quality standards, covering the three major steps of feed manufacturing: feed formulation, feed processing and mixing, and quality control.

Under feed formulation, the user is guided through the types of nutrients required by animals, their sources (raw materials), quality determination, nutrient requirements (feeding standards) and the mathematics of formulation. Feed processing and mixing involves size reduction (milling), mixing, pelleting and crumbing. Quality control involves the testing of raw materials and finished products, and standard operating procedures within the manufacturing plant.

This manual is targeted at small-scale feed manufacturers that need initial information prior to venturing into this business. It will also benefit farmers interested in making homemade feeds.

Chapter 1: The importance of quality feeds

1.1 What is quality feed?

Quality animal feed allows a defined class of livestock to perform optimally. It is i) nutritionally balanced and meets the requirements for the specified production outcome (eggs, milk, growth etc.); ii) palatable and digestible, where the expected intake is achieved; and iii) the ingested nutrients are available for utilization. Animals fed on a quality feed will perform as per the expectation of the farmer. In addition to providing vital nutrients, feed must be safe and free from hazards. A lack or excess of nutrients can lead to severe health problems.

The quality of a feed can be determined systematically through physical examination (e.g. colour, texture and particle size), chemical analysis (proximate analysis, aflatoxins) and animal performance trials.

1.2 Benefits of quality feeds

Well-balanced feeds enable animals to maximize productivity and produce high-quality products. Farmers whose animals achieve production targets will be satisfied customers who will be loyal to the brand.

1.3 Assurance of feed quality

To ensure that only quality feed is delivered to the consumer, the feed manufacturer must put in place quality control mechanisms which assure the use of quality raw materials, controlled manufacturing processes and the quality of the finished product (i.e. it meets standards and is free from any harmful chemical substances or pathogenic microorganism).

The feed manufacturer must be aware of the legal standards of feed quality as contravening these can be punishable by law.

1.4 Feed quality tracking

For a manufacturer to effectively track the quality of a finished product, there is a need to identify all critical points where a hazard can occur and determine the risk level and controls required. This is contained in the Good Manufacturing Practices (GMP) for animal feeds.

Chapter 2: Nutrients

The formulation of rations requires an understanding of the nutrients required by animals, and their functions. All nutrients required by the body are derived from consumed feed.

Nutrients provide nourishment to an animal and are essential for maintenance and production (e.g. growth, milk, reproduction and eggs).

The four basic nutrients required in the diet are energy, protein, minerals and vitamins. Energy and protein are needed in large quantities, and should form the larger portion of a ration, while minerals and vitamins are required in smaller quantities. All are essential for maintenance and production. Although water is not a nutrient, it's requirement cannot be underestimated.

2.1 Energy

Energy is defined as the capacity to do work and is used to maintain essential functions and perform physical tasks. Quantitatively, energy is the most important nutrient in an animal's diet. To the animal, work refers to production (growth (meat), milk, eggs, pregnancy, wool) and maintenance (breathing, heartbeat, digestion, maintaining temperature). Energy deficiency results in slow growth in the young with a delayed onset of puberty, decline in production and marked loss of bodyweight.

The main sources of energy are carbohydrates (cereal grains and their by-products) and lipids (fat), although protein can provide energy under starvation conditions.

Unit: calorie (the amount of energy required to raise the temperature of 1g of water by 1°C). The SI unit is the Joule (1 cal = 4.18 joules). It can be expressed as: cal, kcal, mcal, J, KJ or MJ.

2.1.1 Carbohydrates

While there are many types of carbohydrate, the basic compound that is broken down to provide energy in the body is glucose. Other carbohydrates are ultimately converted to glucose from which many other compounds are synthesized.

In forage, carbohydrates can make up 50% of dry matter while in cereal grains they can account for up to 80%.

In a ration, carbohydrates serve as a source of energy, but there is no specific requirement for any individual carbohydrate compound. Piglets and calves are not able to utilize sucrose, while adult pigs are not able to fully utilize lactose.

Types of carbohydrates

Simple: glucose, fructose, galactose, maltose, lactose and sucrose. All are easily digestible by all animals.

Complex (polysaccharides): glycogen, starch, cellulose and hemicellulose. Starch is the most important non-fibrous polysaccharide in plants, particularly in cereals and tubers. Starch is made of long chains of glucose and is highly digestible by animals (ruminants and non-ruminants).

Cellulose and hemicellulose are the most important fibrous polysaccharides and form the structures that support plants. Cellulose is made of glucose units such as starch, but the glucose is linked in such a way to make cellulose insoluble and difficult to degrade in the gut of non-ruminants. Microorganisms found in the rumen (in cows, sheep and goats) possess the necessary enzymes to break down cellulose and hemicellulose.

Lignin forms part of the structural component of plant tissues and increases with the age of the plant. It is not a carbohydrate but is closely associated with cellulose and hemicellulose. It is indigestible and interferes with the digestion of cellulose and hemicellulose in ruminant feeds. Lignin is concentrated in plant stems, and high lignin values are an indication of poor-quality feed.

2.1.2 Lipids

Lipids (fats) are organic compounds that are insoluble in water but soluble in organic solvents (e.g. petroleum, ether). They serve as a concentrated form of stored energy (1 gram of fat yields 9.45 kcal on combustion compared to 4.1 kcal for carbohydrates). Fats are solid at room temperature while oils are liquid.

Fats are composed of fatty acids of varying chain length (2–24 carbons) and one molecule of glycerol. They are referred to as mono-, di- and tri-acylglycerols depending on the number of fatty acids present.

If all the available positions on the carbon chain are occupied by hydrogen, the fat is saturated. If one or more double bonds are present (in place of hydrogen) the fat is unsaturated. Unsaturated fats are more prone to oxidation and becoming rancid than saturated fats and cannot be stored for long except under cold temperatures or in the presence of an antioxidant.

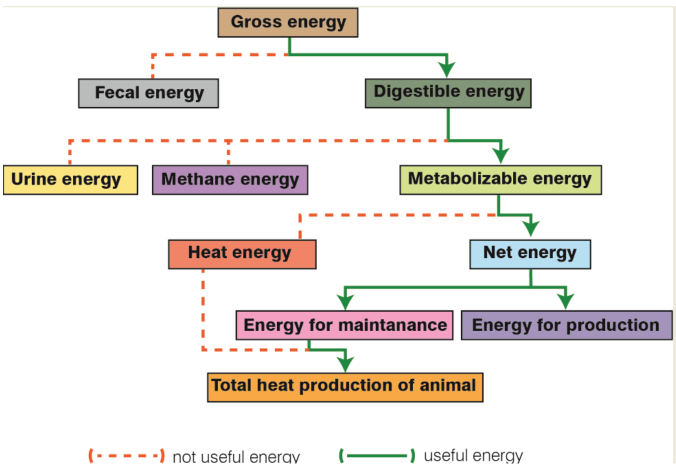
Animals can synthesize a large amount of fat with a minimal fat intake as carbohydrates and some amino acids (from protein) can be used for fat synthesis. As such, fat inclusion in the diet is not essential.

Linoleic and linolenic are 2 fatty acids that are essential in the diet of non-ruminants at a level of about 1% of the energy in the diet. They are required in the synthesis of special compounds in the body. These are normally present in fats present in plant based ingredients in animal feeds and deficiency is very unlikely.

2.1.3 Energy partitioning

When energy is consumed by the animal, its efficiency of utilization is not 100%. Some is lost in the process of digestion and other processes. The energy is partitioned into different forms (Figure 1).

Figure 1: Partitioning of energy consumed by animals.



Gross energy (GE) is the total amount of energy contained in a feedstuff. It is determined using a bomb calorimeter which measures the heat produced after the complete combustion of the feedstuff. However, the value is not particularly useful since the gross energy of a poorly digested feed (where most of the energy is lost in faecal material) can be equal to that of a highly digestible feed.

Digestible energy (DE) is the amount of energy absorbed by the animal after consuming a particular feedstuff. It is obtained by subtracting faecal energy (gross energy of faeces) from gross energy of feed. It is used during the formulation of pig diets.

Metabolizable energy (ME) is determined by subtracting energy lost in urine and combustible gases (in ruminants) from digestible energy. It is difficult to obtain except in birds (poultry) since they void both urine and faeces together and the energy lost through gases is negligible. It is commonly used during feed formulation for poultry.

Net energy (NE) is the energy available for maintenance and production (including growth). It is measured by subtracting energy lost as heat from ME. It is more accurate than digestible energy and ME, but values are not available for many feedstuffs. It is commonly used during the formulation of dairy cattle diets.

2.2 Protein

Proteins are vital to animals and must be provided in the diet. Proteins are organic nitrogenous compounds composed of one or more long chains of amino acids. They are essential constituents of the tissues of all biological organisms. Without protein synthesis, life could not exist.

Functions of proteins: all cells in the animal body contain different types of protein whose key functions include building and repairing body tissues, synthesis of protein contained in secreted products like milk, hormone production, enzymes synthesis and immune function.

Deficiency signs: slow growth and reduced production.

Main sources: plants (oilseed cakes), animal (blood meal, meat and bone meal), marine (fish meal), avian (feather meal).

Many types of proteins are found in the animal body, from insoluble (feathers, hooves, hair) to soluble (enzymes). Each protein has a distinctive function in the body e.g. protection (hair, wool), metabolism (enzymes, hormones) and movement (muscle).

Plant and animal proteins generally contain 20 amino acids (Table 1). Animals can only synthesize some of these (non-essential), and the essential amino acids must therefore be supplied in the diet of most animals (not to ruminants, which have microbes in the gut).

Table 1: List of essential and non-essential amino acids

Essential amino acids	Non-essential amino acids
Arginine	Alanine
Histidine	Aspartic acid
Isoleucine	Glutamine
Leucine	Glutamic acid
Methionine	Glycine
Lysine	Asparagine
Phenylalanine	Proline
Threonine	Serine
Valine	Tyrosine
Tryptophan	Cysteine

In compounded commercial concentrates, the amino acids most likely to be deficient are methionine, lysine and tryptophan, as cereals and their by-products (maize, wheat, etc.) which are the common energy sources have a shortage of these. When large amounts of cereals are included in feed, the feed requires supplementation with protein sources high in these amino acids. Most common plant-based protein supplements are low in lysine and/or methionine.

An ideal ration is that in which no amino acid is lacking. An amino acid imbalance results in the poor utilization and wastage of consumed protein, which is expensive in terms of both money (proteins are expensive) and body energy (which is required to excrete unused protein).

Proteins consumed in the diet are broken down into constituent amino acids in the gut which are absorbed. The efficient re-utilization of absorbed amino acids for the synthesis of body protein is related to the distribution of essential amino acids in the consumed protein. Therefore, a protein that supplies essential amino acids at levels required by the body is of higher quality (i.e. maize protein compared to fish meal protein).

Ruminants (e.g. cattle, sheep and goats) do not require dietary amino acids to the same extent as non-ruminants, as ruminal microorganisms synthesize both essential and nonessential amino acids.

Proteins are hydrolysed into amino acids in the rumen, which are further broken down into organic acids and ammonia. The ammonia is then used by microbes to synthesize new protein. The protein that reaches the duodenum for absorption (microbial protein) is therefore different from that which is consumed. The microbial protein is of lower quality than dietary protein of animal origin (thus downgraded) but is of better quality than most proteins of plant origin (thus upgraded) and is superior to non-protein nitrogen (NPN).

The value of protein to ruminants is related to solubility (degradability) in the rumen. Some proteins such as fish meal are not degraded to a large extent (they bypass rumen degradation and are referred to as 'bypass protein') and pass to the duodenum where they are digested to supply amino acids such as lysine and methionine (which may be low in the microbial protein).

However, high yielding dairy cows may not be able to generate adequate amounts of lysine and methionine from gut microbes and may require supplementation. When formulating rations for ruminants, the amino acid content is not a major consideration.

2.2.1 Utilization of non-protein nitrogen (NPN) by ruminants

NPN compounds such as urea can be included in ruminant rations due to the ruminants' ability to convert urea to ammonia which can be used by rumen microbes for synthesis amino acids. NPN compounds cannot be fed to non-ruminants.

However, in ruminants, high levels of urea can lead to toxicity due to ammonia accumulation in the blood leading to poisoning. This is especially so in those animals that are fed poor quality roughage diets which cannot supply the energy required to capture the ammonia fast enough. The inclusion of urea in feed should therefore be done with care mostly in combination with molasses which supplies the required energy fast enough to avoid ammonia accumulation. The practice of feeding poultry manure to cows is driven by the presence of uric acid (similar to urea) in poultry manure.

Recommendations for urea inclusion in dairy cow concentrate**:** 1.5%.
Max daily allowance per cow (given in graded amounts to allow adaptation): 200 g

2.3 Minerals

Minerals, though required in smaller amounts than energy and protein, play key metabolic roles in the body. They are classified into major and micro (trace) minerals depending upon their concentration in feeds and requirements of the animal. Nutritionally important essential minerals are shown in Table 2.

Table 2: Minerals to be included in livestock diets

Major minerals	Trace minerals
Calcium (Ca)	Iron (Fe)
Phosphorus (P)	Zinc (Zn)
Potassium (K)	Copper (Cu)
Sodium (Na)	Molybdenum (Mo)
Chlorine (Cl)	Selenium (Se)
Sulphur (S)	Iodine (I)
Magnesium (Mg)	Manganese (Mn)
	Cobalt (Co)

Major minerals

The major minerals and their roles are summarized in Table 3.

Table 3: Major minerals required by animals

Mineral	Comment
Calcium	Ca is the most abundant mineral element in the animal body. It is an important constituent of the skeleton and teeth, where 99% of total body calcium is found. It is a major constituent of eggshell.
Phosphorus	P plays an important role in bone formation but to a lesser extent than calcium. It plays an important role in energy metabolism.
Potassium	K is important, along with sodium, chlorine and bicarbonate ions, for the regulation of body fluids.
Magnesium	Mg is mostly found in the skeleton (70%) and in soft tissues and fluids. It is a key element for the normal functioning of cells and is the most common enzyme activator.
Sodium	Na is mostly present in soft tissues and body fluids. Like potassium, sodium is concerned with the regulation of body fluids. Sodium plays a role in the transmission of nerve impulses and in the absorption of sugars and amino acids from the digestive tract.
Chlorine	Cl is associated with sodium and potassium in osmotic regulation. It plays an important part in gastric secretion.
Sulphur	S is required for growth and is a major component of wool.

Trace minerals

Trace minerals that should be included animals feeds and their roles are shown in Table 4.

Table 4: Minor minerals required by animals

Mineral	Comment
Iron	Fe occurs in blood serum in the protein transferrin which transports it around the body. It combines with proteins to form haemoglobin, a protein needed to transport oxygen in the blood.
Copper	Cu together with iron, is a component of proteins involved in oxygen metabolism. It is also involved in bone formation, wool growth and pigmentation
Cobalt	Co is required by microorganisms in the rumen to be a component of vitamin B12, also known as cobalamin. Vitamin B12 is an essential cofactor for the function of enzymes.
Iodine	I is important for the synthesis of hormones.
Manganese	Mn is an activator of many enzymes.
Zinc	Zn is involved in cell replication and occurs in high concentrations in skin, hair and wool.
Selenium	Se reduces the amount of vitamin E required to maintain cell functioning

2.4 Vitamins

Vitamins are organic compounds which are required in small amounts for the normal growth, production and maintenance of animal life. Although they are required in small amounts, a continuous deficiency in the diet can result in metabolism disorders and eventually deficiency syndromes.

Many vitamins are destroyed during storage, especially if exposed to high temperatures, light, and certain metals such as iron. Hence, the conditions under which feed is stored affects the vitamin's potency.

Vitamins are divided into two groups: fat-soluble and water-soluble (Table 5). The requirement of vitamins is given in International Units (IU). The precise definition of an IU differs between vitamins.

Table 5: Fat and water soluble vitamins required by livestock

Vitamin		
Fat-soluble vitamins		
A	Retinol	This is available in most green plants, and if animals graze on well managed pastures and forage, deficiencies will not occur. However, cattle fed on poor quality roughage such as poor-quality hay and straw require supplementation.
D2	Ergocalciferol	There is little vitamin D in plants, and animals obtain most of it by synthesizing the vitamin in the skin by the action of ultraviolet rays from the sun. It is involved in the absorption of calcium and phosphorous from the intestines and the deposition of the minerals in bone, together with the maintenance of normal blood levels. Vitamin D deficiency in young calves is likely to occur when they are housed in houses with dim light and offered poor quality diets.
D3	Cholecalciferol	
E	Tocopherol	Found mostly in the oily parts of the cereal germs and oilseed cakes (e.g. sunflower)
K	Phylloquinone	This is synthesized by ruminal microorganisms and is readily available in leafy forage. Vitamin K is involved in blood-clotting mechanisms
Water-soluble vitamins		
B complex:		Available from animal or marine sourced ingredients and plant-based ingredients including cereals and cereal based by-products.
B1 B2 B6 B12	Thiamine Riboflavin Pyridoxine Cyanocoba-lamin	
Others		This group of vitamins is synthesized by microorganisms in the rumen and is absorbed by ruminants. Some are also synthesized by gut-based microorganisms in livestock.
	Pantothenic acid Biotin Folic acid Nicotinamide	
C	Ascorbic acid	This is produced in tissues of all farm livestock and a dietary supply is unnecessary.

Chapter 3: Raw materials: quality, processing and preservation

Animal feedstuffs are natural or artificial material, which when included in the diet serve as a nutrient source or have other useful functions. Animal feedstuffs are classified into either roughage or concentrates. Roughage includes pastures, forage, hay, silage, and crop by-products that contain a high percentage of fibre. Concentrates are low in fibre and high in energy or protein. During commercial feed making, raw materials consist almost entirely of concentrates.

Concentrates can be classified based on their nutrient contribution to the ration: as a source of energy, protein, minerals, or vitamins. The use of a given concentrate in a livestock feed depends on the following factors:

Availability. This is the first major consideration and largely depends on location and season.

Cost. As livestock are kept for profit, the prevailing price of a feedstuff is a key consideration for its inclusion. The price will depend on ease of availability, especially for plant-based material, which may be seasonal.

Competition with human consumption. Several cereal grains used as feedstuffs in developing countries are primarily grown for human consumption, with the excess sold for livestock use. During times of scarcity, some of these materials may not be available.

Acceptability/utilization. The acceptability and ability of the animal to utilize (digest) a feedstuff is important. Some feedstuffs can only be fed to certain species of animals due to the nature of their digestive systems.

Nutritional value. The choice of feedstuff can be dictated by its nutrient content. During costing, the nutritional value should be considered, and the purchase price based on quality.

Handling properties. Some feedstuffs require processing prior to mixing (e.g. for size reduction) and their usage will depend on the capacity to process (e.g. milling of cottonseed cake [CSC]).

Presence of anti-nutritive factors. Some feedstuffs contain factors that are harmful to some classes of livestock and are unsuitable.

3.1 Energy feedstuffs

Energy feedstuffs have a high energy content per unit weight and are normally mixed with other feedstuffs (which are concentrated sources of other specific nutrients) to provide additional energy to help complete a balanced diet. They normally comprise less than 18% crude fibre, less than 20% crude protein (CP), and mineral and vitamins to a small extent. Cereal grains, cereal milling by-products, molasses and fats are all energy feedstuffs.

3.1.1 Cereal-based concentrates

In developed countries, some cereal grains are grown exclusively for animal feed. In developing countries, their milled by-products are a major ingredient due to a significant competition for grain used for human consumption.

The most commonly used cereal grains have some similarities:

Dry matter content 85–90%. Low dry matter content is a sign of poor drying and makes grains susceptible to mould growth and aflatoxin contamination.

ME of approximately 3,000 kcal/kg. Mostly in the form of starch

CP 8–12%. Most protein is found in the outer parts of grain. Lysine and methionine levels are usually low; digestibility of the protein is 75–80%.

Crude fat 2–5%. High in mono- and poly-unsaturated fatty acids (oleic, linoleic and linolenic acids).

Crude fibre 6–18%. Crude fibre is high in grains which have a husk (oats, rice, barley) and low in naked grains (wheat, maize).

Calcium (<0.15%). Ca content is low in cereal grains.

Phosphorous (0.30–0.5%). P level is high in cereal grains. About 50% of phosphorous in the feeds of plant origin is bound and unavailable to non-ruminants.

Maize

Maize is the most important cereal in East Africa and is a staple for humans. The common variety has a white grain, but it can be yellow, which contains beta carotene, a precursor of vitamin A. Inclusion of yellow maize can give broiler carcasses and egg yolks a deep yellow colour, which is desirable to consumers.

Maize is an excellent source of digestible energy for both ruminants and non-ruminants. It is low in the amino acids tryptophan and lysine, which require supplementation in non-ruminant rations.

Whole maize is included in poultry and swine rations. When maize is dry milled for human consumption, several by-products are obtained. The nutrient content of the maize grain is shown in Table 6.

Table 6: Nutrient content of maize

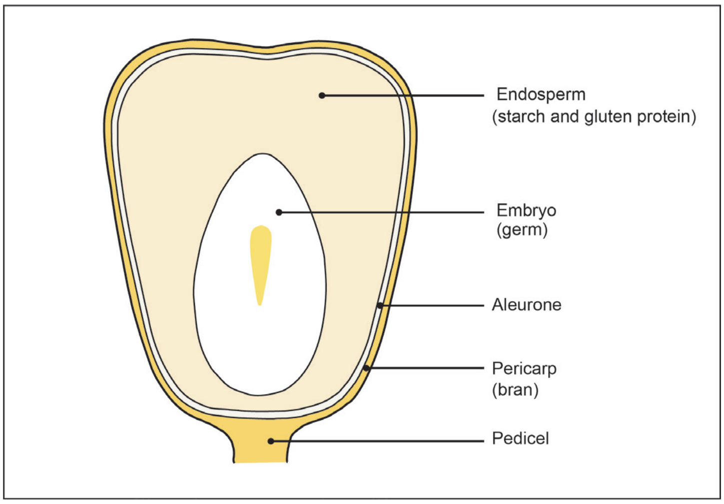
ME (poultry)	DE (Pigs)	CP	CF	EE	Ca	T P	A P
Kcal/kg	Kcal/kg	%	%	%	%	%	%
3,300	3,400	8–12	3.0	3–6	0.02–0.05	0.24–0.33	0.1

CP: Crude protein, CF: Crude fibre, EE: oil content, Ca: Calcium, TP: Total phosphorous, AP: Available phosphorous

Maize by-products:

Maize undergoes dry milling to produce flour from the endosperm for human consumption (Figure 2). In the process, the hull, germ, and endosperm are separated before milling. The main by-products of maize milling are maize bran and maize germ.

Figure 2: Parts of the whole maize grain.



Source: Simon Ndonye.

Maize bran

Maize bran consists of the outer coating of the maize kernel (hull) with little or no starchy part and germ.

Maize germ

The maize germ consists of an oil-rich (high energy) embryo and protein. After the oil is mechanically extracted from the germ, the residue is maize germ cake. The residue after solvent extraction is called maize germ meal. Cake has high oil content and is higher in energy, while meal is low in oil and is considered a protein supplement.

Wheat

Wheat is grown primarily for human consumption and is rarely used for animal feed due to its high cost. Several by-products of milled wheat are used for livestock feeding.

The proteins found in wheat are prolamin and glutelin (both referred as wheat gluten). Wheat gluten is elastic and forms a sticky mass when chewed, reducing palatability in livestock. Wheat has higher protein content than maize and provides only slightly less energy.

Wheat contains 5–8% indigestible pentosans (non-starch polysaccharides) leading to reduced diet digestibility and wet faeces. The main pentosans are arabinoxylans which absorb up to 10 times their weight in water. Poultry do not have adequate enzymes to digest these polysaccharides which lead to an increased digesta viscosity and reduction of 10–15% ME utilization. This problem can be solved by adding an exogenous xylanase enzyme to feed. The nutrient content of the wheat grain is shown in Table 7.

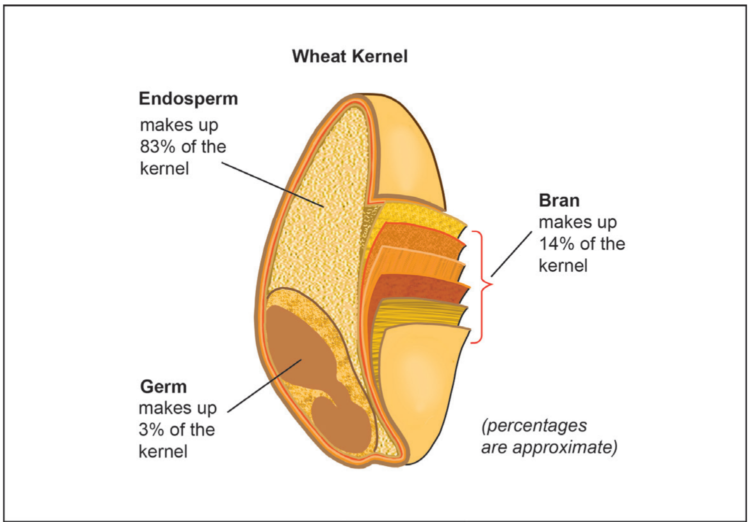
Table 7: Nutrient content of wheat

ME (poultry)	DE (pigs)	CP	CF	EE	Ca	T P	A P
Kcal/kg	Kcal/kg	%	%	%	%	%	%
3,000	3450	13	3.0	2.0	0.06	0.35	0.15

CP: Crude protein, CF: Crude fibre, EE: oil content, Ca: Calcium, TP: Total phosphorous, AP: Available phosphorous

Wheat grain comprises 83% endosperm, 14% bran and 3% germ. During milling for human consumption, the endosperm is separated from the bran and germ (Figure 3).

Figure 3: Parts of wheat grain.



Source: Simon Ndonye.

Wheat by-products

Wheat is normally grown for human food. During the milling process, several by-products used for livestock feed are obtained.

Wheat bran

Wheat bran consists of the coarse outer covering of the wheat grain. It is made up of the husk and some adhering endosperm. It has a low energy value (for non-ruminants) and high fibre content, making it highly suitable as cattle and horse feed, as the fibre is readily digestible (Table 8). It can be used for feeding pigs and poultry in limited amounts due to high fibre and low ME.

Table 8: Nutrient content of wheat bran

ME (poultry)	DE (pigs)	CP	CF	EE	Ca	T P	A P
Kcal/kg	Kcal/kg	%	%	%	%	%	%
1,500	2,500	16	12	3	0.15	1.3	0.5

CP: Crude protein, CF: Crude fibre, EE: oil content, Ca: Calcium, TP: Total phosphorous, AP: Available phosphorous

Wheat pollard (middlings)

Wheat pollard consists of part of the endosperm, germ, bran particles, and some flour and accounts for 40% of milling by-products. Appearance is that of a brownish, finely ground meal. It is low in fibre, high in protein and energy, and highly suitable for pigs and poultry (Table 9). It is not as palatable as bran due to its tendency to form a pasty mass in the mouths of animals when chewed.

Table 9: Nutrient content of wheat pollard

ME (poultry)	DE (pigs)	CP	CF	EE	Ca	T P	A P
Kcal/kg	Kcal/kg	%	%	%	%	%	%
2,200	2500	12	7.5	3.0	0.12	0.85	0.3

CP: Crude protein, CF: Crude fibre, EE: oil content, Ca: Calcium, TP: Total phosphorous, AP: Available phosphorous

Barley

Barley is primarily grown for beer making, and only reject barley is used for feeding livestock. The hull, which surrounds the grain, constitutes 14% of the total grain mass and increases the crude fibre content of the grain (Figure 4). The grain contains more total protein and higher levels of lysine and methionine compared to maize or sorghum, but its energy value is lower due to its lower starch content, higher fibre, and lower digestibility (Table 10).

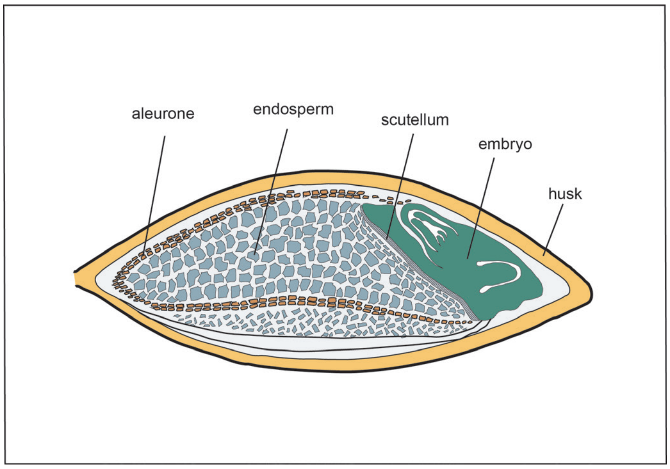
Table 10: Nutrient content of barley

ME (poultry)	DE (Pigs)	CP	CF	EE	Ca	T P	A P
Kcal/kg	Kcal/kg	%	%	%	%	%	%
3,110	3,600	11–12	6.3	2.5	0.1	0.36	0.16

CP: Crude protein, CF: Crude fibre, EE: oil content, Ca: Calcium, TP: Total phosphorous, AP: Available phosphorous

Whole barley is not suitable for pigs or poultry due to the high fibre. Steam rolled barley is especially suitable for ruminants.

Figure 4: Parts of a barley grain.



Source: Chetrariu and Dabija 2020.

Barley contains non-starch polysaccharides beta-glucans, which cause problems with digesta and excreta viscosity as birds are unable to digest glucans. The increased viscosity of digesta results in a reduction of ME utilization. Mixing with beta-glucanase enzymes (as additives) solves this problem.

Barley by-products

During the malting of barley for beer making, several by-products suitable for animal feedstuffs are produced.

Multiculms (multi-sprouts)

These are the sprouts and rootlets obtained from germinated barley during the malting process. A large proportion of the protein takes the form of NPN, and the material is therefore more effectively utilized by ruminants.

Table 11 presents the nutrient contents of barley multiculms.

Table 11: Nutrient content of barley multiculms

ME (poultry)	NEl (Cattle)	CP	CF	EE	Ca	T P	A P
Kcal/kg	Kcal/kg	%	%	%	%	%	%
2,900	1,620	24	13.5	2.2	0.23	0.75	0.3

CP: crude protein, CF: crude fibre, EE: oil content, Ca: Calcium, TP: total phosphorous, AP: available phosphorous

Wet brewers' grain

Wet brewer's grains are the insoluble residue after removal of fermented liquid from malted barley. The material is fed when wet and can quickly become rancid. It should be fed immediately or ensiled (in combination with other drier materials such as bran, forage, or hulls to reduce excessive runoff).

The main constraint in the use of brewer's grains is the cost of transporting the wet material. It is considered an excellent supplement for dairy animals.

Dried brewer's yeast

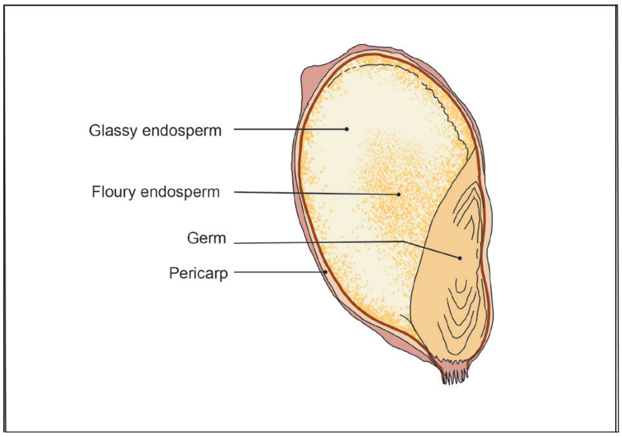
Dried yeast (Saccharomyces) is a by-product of brewing beer and ale. It is particularly rich in highly digestible protein (42% CP), useful for all classes of livestock, and a good source of vitamin B and phosphorus.

Care should be taken as a proportion of the nitrogen is in the form of NPN. It is recommended for ruminants.

Sorghum

Sorghum is grown primarily for human food but can be used as livestock feed depending on availability and cost. Sorghum withstands drought better than most grain crops and is therefore grown in areas where maize does not perform well. The grain is small, relatively hard and should be fed to cattle and horses in ground form to break the seed coat and increase digestibility (Figure 5).

Figure 5: Parts of a sorghum grain.



Source: Simon Ndonye

There are two varieties, the brown (bitter) and white (highly palatable). Brown sorghum is bird resistant due to the presence of tannins, which makes it suitable in areas where birds are a problem. The tannins however reduce digestibility and animal performance, meaning brown sorghum should only be fed in low quantities, especially to poultry.

Nutritionally, sorghum resembles maize and can be used to replace maize in compounded livestock feed. However, it lacks the colour pigment xanthophylls found in yellow maize.

The nutrient contents of sorghum is presented in Table 12.

Table 12: Nutrient content of sorghum

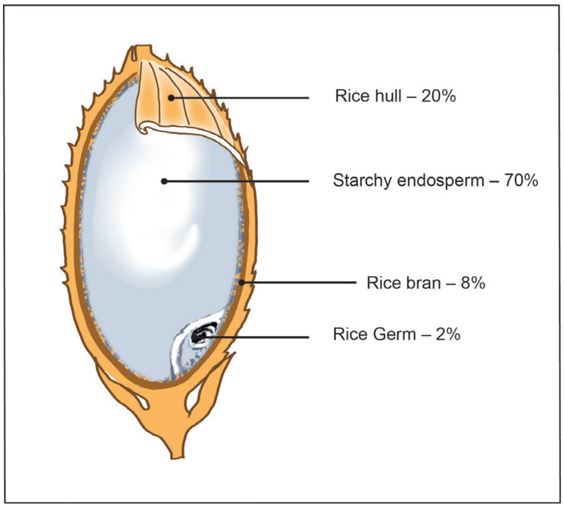
ME (poultry)	DE (pigs)	CP	CF	EE	Ca	T P	A P
Kcal/kg	Kcal/kg	%	%	%	%	%	%
3,200	3,400	12	3	3.5	0.04	0.45	0.15

CP: crude protein, CF: crude fibre, EE: oil content, Ca: Calcium, TP: total phosphorous, AP: available phosphorous

Rice

Rice is grown exclusively for human food. In rice growing areas, only rice that is unfit for human consumption is used as animal feed. The whole rice paddy is shown in Figure 6.

Figure 6: Parts of a rice grain.

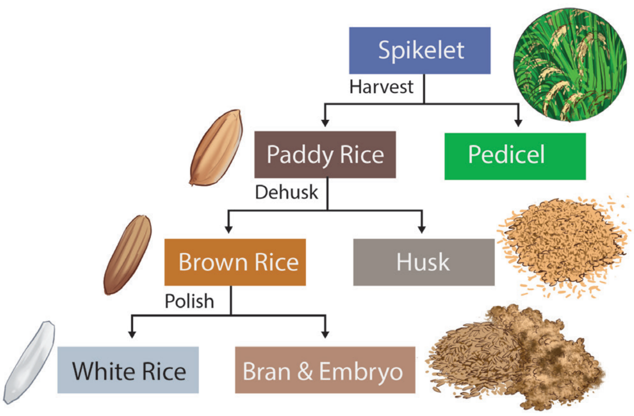


Source: Adapted from Grande Rice Bran Oil (2017).

Rice by-products

During the processing of rice (both white and brown) for human consumption, several by-products are obtained which are used as livestock feed (Figure 7).

Figure 7: Rice processing and by-products.



Source: Rice Processing (nd).

Rice hulls

Rice hulls have a very low nutritive value, are particularly fibrous, and should not be given to animals without milling, as this irritates the intestine. They can make up 20% of the total weight of the grain. Due to the high fibre content, they are of low digestibility and therefore of little value and should not be used in compounded animal feeds. The removal of the hull from the grain results in brown rice.

Rice bran

Rice bran is a by-product of the rice milling process (the conversion of brown rice to white rice) and consists of the pericarp, aleurone layer, germ, and some endosperm. It is highly palatable when fed fresh but becomes rancid when kept in storage due to its high fat content (6–10%). It is high in B complex vitamins. It can be fed to all classes of livestock (not more than 30% in pig rations and 40% in poultry). The nutrient contents of rice bran is presented in Table 13.

Table 13: Nutrient content of rice bran

ME (poultry)	ME (pigs)	CP	CF	EE	Ca	T P	A P
Kcal/kg	Kcal/kg	%	%	%	%	%	%
2,700	3,100	12.5	13	10–13	0.06	1.5	0.34

CP: crude protein, CF: crude fibre, EE: oil content, Ca: Calcium, TP: total phosphorous, AP: available phosphorous

3.1.2 Non-cereal-based concentrates

Cane molasses

Molasses is a by-product of the manufacture of refined sugar from beet and sugar cane containing sucrose and other soluble sugars. It can be used for distilling industrial alcohol and livestock feed. Animals like to eat molasses but levels beyond 25% can cause digestive disturbances (diarrhoea) and reduced feed efficiency.

Molasses has been used to induce animals to eat poor quality roughage by mixing with water and sprinkling on feedstuffs). Cane molasses is fed mainly to dairy cows, beef, sheep, and horses, and rarely to pigs and poultry. Fed at low levels, molasses is a good source of energy and can replace some grain content (Table 14).

Molasses helps to reduce dust in feed, as a pellet binder, or liquid protein supplement when mixed with urea. Due to its milling properties (sticky consistency), the use of molasses in feed manufacturing is limited as its high viscosity will not allow it to circulate easily from storage tanks to feed mixers.

Table 14: Nutrient content of cane molasses

Dry matter	ME (poultry)	ME (cattle)	CP (%)	Ca	TP
%	Kcal/kg	kcal/kg %	%	%	%
75	2,400	2,650	6	1	0.1

CP: crude protein, CF: crude fibre, EE: oil content, Ca: Calcium, TP: total phosphorous, AP: available phosphorous

Fats and oils

The essential fatty acid requirements of animals are normally supplied in sufficient amounts by natural feedstuffs and supplementation is usually not necessary. Fats do not contain other nutrients and are a concentrated source of energy (containing 2.25 times more energy than carbohydrates per unit weight). The addition of fat to livestock feeds is practiced for a variety of reasons.

These include:

- To supplement energy supplied by cereal-based concentrates. High yielding dairy cows and broiler chickens may not be able to derive enough energy from cereals to meet their dietary requirements due to limitations in stomach size in broilers, and digestive upsets in cattle.
- To improve palatability by reducing dustiness.

High levels of fat in diets can lead to rancidity and require the addition of antioxidants. The inclusion of fat should be limited to less than 7% of the total ration for dairy cows due to the harmful effects on rumen microorganisms at higher inclusion level.

The main source of fat for animal feed is from slaughterhouses and rendering plants. Used vegetable oil (yellow grease) can be sourced from fast food eateries.

3.2 Protein concentrates

Protein concentrates contain 20% or more CP and are used in feed formulations to increase the protein levels of the feed mix. It should be noted that most energy sources (except fat and starch) supply protein, but usually not in enough quantities to meet the animal's requirements. Unlike energy, protein is defined in terms of both quality and quantity, and as such, some supplements may contain the same amount of protein but differ markedly in quality and price. The quality is dependent on the presence of essential amino acids.

The protein requirements for livestock can be met from several sources, including:

- Plants (high protein legume fodder, oilseed meals and cakes)
- By-products from the wet milling of maize
- Brewery and distillery by-products (yeast)
- Animal, avian, or marine
- NPN (urea)

The choice of the source to use is dependent on several factors as shown in Table 15.

Table 15: Factors determining inclusion of protein concentrate in rations

Factor	Comment
Availability	Varies from location to location
Cost factor	Cost of protein supplement.
Quality	Content and availability of essential amino acids.
Nutritional value	Choice of feedstuff can be dictated by nutrient content. Nutritional value should be considered during costing, and purchase price based on quality. Presence of minerals and vitamins may be a decisive factor as proteins sources may resemble each other but may different mineral and vitamin levels.
Undesirable and anti-nutritive factors	The presence of trypsin inhibitors in soybean, gossypol in CSC and odours in products such as fishmeal.

3.2.1 Plant protein sources

The most common plant protein sources used in feed mixing are oilseed meals and cakes. Other sources include maize gluten feed and meal, germ meal (maize), copra meal (coconut), canola meal, and peanut meal.

In general, plant proteins are:

- Low in lysine, methionine and cysteine (Soybean is an exception with high lysine)
- High in true protein (Plant proteins have about 90% true protein and 10%NPN)
- Dependent on the method of fat extraction which affects the energy content of oilseed meals
- High in phosphorous, although most is bound by phytic acid.

Oilseed cakes and meals

These are by-products of fat extraction from seeds high in oil content. The oil can be extracted mechanically through a press or extracted using organic solvents. Mechanically extracted oil is normally in cake form, while solvent extracted oil is in meal form (Figure 8).

Figure 8: Cottonseed cake (A), Cottonseed meal (B).

Source: Courtesy of IndiaMART InterMESH Ltd and Protinex Advanced Feed Industries (n.d).

Mechanically extracted cakes are high in residue fat and low in protein, while the opposite applies to solvent extracted meal.

Soybean meal

Whole soya bean is low in CP (38%) and rich in oil (18–21%) and is extracted to make soybean meal (Table 16). After the extraction of oil (soybean meal through solvent extraction), the protein content of the meal increases to 46–50%, becoming palatable and highly digestible. Soybean meal is high in lysine but low in methionine. It is the best plant protein source and should be a standard ingredient in poultry diets when available.

Raw soybeans have a lower nutritive value than roasted beans or soybean meal due to the presence of toxic substances. The anti-nutritive factors in raw soybean include trypsin inhibitors that impede the activity of the enzymes trypsin and chymotrypsin in the gut, thus preventing protein digestion and increasing nitrogen and sulphur losses in faeces. This leads to poor growth, and poor feather production in poultry.

These toxins are especially harmful to young animals (calves, chicks and piglets). Laying chicken fed raw beans will lay eggs normally, but with blood spots in the yolk.

- The toxin is destroyed through extrusion, as the inhibitor is thermally labile. Under small-scale conditions, the trypsin inhibitor can be controlled by simply germinating or fermenting the bean for 48 hours. Small quantities of soya bean can be roasted at a homestead level, before being crushed and fed to livestock.

Soybean can be processed into several products:

- Full fat soybean meal: beans are heated, extruded, and ground. Due to a high fat content (unsaturated fatty acids), it produces fatty carcasses in broiler chickens. It is prone to rancidity. Extruded full-fat soybeans have the same amount of protein and oil as whole beans but lower moisture content. By using extruded full-fat soybean meal in poultry feed there is no need for added fat.
- Soybean cake/meal: oil is extracted from the bean (mechanically or by solvents) and cake milled.
- Dehulled soybean meal: beans are dehulled prior to oil extraction, resulting in a meal with more protein and less fibre. This product is used in human foods and for young animals (e.g. in milk replacer for calves, and chicks).
- Soy protein concentrate: this is produced when dehulled and fat extracted beans are leached with water to remove water-soluble, non-protein constituents. This product contains up to 70% CP and is used to produce soya products resembling meat for human consumption.

Table 16: Nutrient content of soybean meal

DM	ME poultry	DE pigs	CP	EE	CF	Ca	TP	AP	Lys	Met
%	Kcal/kg	Kcal/kg	%	%	%	%	%	%	%	%
90	2,300	3200	45	1	7	0.3	0.58	0.3	2.69	0.62

DM: dry matter, CP: crude protein, CF: crude fibre, EE: oil content, Ca: Calcium, TP: total phosphorous, AP: available phosphorous, Lys: Lysine, Met: Methionine

Cottonseed cake

The cake is obtained after oil has been pressed from the cottonseeds either mechanically (CSC) or by solvents (cottonseed meal). Whole cottonseed is high in energy and low in protein. Its use in feeding early lactating cows has met with good results, due to a high energy (fat) content and highly digestible fibre (Table 17).

The protein is of good quality, but the content is variable due to processing techniques, as the fibre levels are highly dependent on the efficiency of the ginnery. The energy content is dependent on the method and efficiency of fat extraction. As a result, cakes have a high variability in content of energy, fibre, and protein. A cake with a high protein content is considered to be of good quality.

The use of CSC in livestock feed is limited by anti-nutritional factors. It contains **gossypol**, a yellow pigment toxic to young chicks and piglets. The high fibre content, presence of gossypol, low levels cysteine, methionine and lysine limit its use in poultry diets. It is very palatable to ruminant animals but less liked by poultry and swine.

The use of cottonseed in animal feed can be increased through breeding plant types with lower levels of gossypol, removing gossypol by physical extraction, or deactivating it with iron salts.

Low gossypol meals that give a good performance in both poultry and swine are available but are more expensive.

The use of CSC in the rations of laying hens is not recommended, as gossypol affects egg quality, causing a green-brown-black discolouration in the yolk, depending on the level of gossypol and length of storage. It causes yolks to be viscous.

Some fatty acids in residual cotton oil cause egg whites to turn pink during storage.

Table 17: Nutrient content of cottonseed cake

DM	ME poultry	ME ruminants	DE pigs	CP	EE	CF	Ca	TP	AP	Lys	Met
%	Kcal/kg	Kcal/kg	Kcal/kg	%	%	%	%	%	%	%	%
90	2,200	2,700	2,690	34	2	16	0.25	1.0	0.3	1.3	0.7

DM: dry matter, CP: crude protein, CF: crude fibre, EE: oil content, Ca: Calcium, TP: total phosphorous, AP: available phosphorous, Lys: Lysine, Met: Methionine

Sunflower seed cake

Sunflower seed is grown for its polyunsaturated fatty acids and has a typical oil content of 46% and protein content of 16% (Table 18). The cake is obtained after mechanical expulsion of fat from sunflower seeds, with the quality (energy and protein content) of the cake dependent on the extent and efficiency of fat extraction. The nutrient content of the cake varies considerably due to differences in the efficiency of extraction. Sunflower cake is lower in protein and higher in fibre (due to a thick seed coat) when compared with CSC. It is deficient in lysine and methionine. The high fibre content discourages its use in swine and poultry diets, but in ruminants the performance is similar to CSC.

The high protein and low fibre content of dehulled extracted meal makes it suitable for poultry but may not be available in the East African market.

Table 18: Nutrient content of sunflower seed cake

DM	ME poultry	ME ruminants	DE pigs	CP	EE	CF	Ca	TP	AP	Lys	Met
%	Kcal/kg	Kcal/kg	Kcal/kg	%	%	%	%	%	%	%	%
90	1,700	2,300	2,470	28	2	23	0.3	1.2	0.35	1.0	1.0

CP: crude protein, CF: crude fibre, EE: oil content, Ca: Calcium, TP: total phosphorous, AP: available phosphorous

Groundnut (peanut) meal

Groundnuts are dehulled and crushed for their oil for human consumption with whole seeds containing 25–30% CP and 35–60% oil (Table 19). After extraction, meal contains around 7% oil.

If not dried properly, there is a risk of aflatoxin contamination and poisoning. Quality is influenced by processing techniques and presence of hulls. The protein content of groundnut cake can be as high as 45%.

Groundnut cake protein is deficient in lysine and methionine, and has low digestibility, thought to be due to the presence of tannins from the skins.

Table 19: Nutrient content of groundnut (peanut) meal

DM	ME poultry	ME ruminants	DE pigs	CP	EE	CF	Ca	TP	AP	Lys	Met
%	Kcal/kg	Kcal/kg	Kcal/kg	%	%	%	%	%	%	%	%
88	3,100	3,100	4,300	46	6	9	0.2	0.7	0.3	1.4	0.6

DM: dry matter, CP: crude protein, CF: crude fibre, EE: oil content, Ca: Calcium, TP: total phosphorous, AP: available phosphorous, Lys: Lysine, Met: Methionine

Copra (coconut meal)

Copra meal is the flesh of the coconut kernel after oil extraction and drying. The oil is extracted mechanically or by using solvents. Mechanically extracted cake has a high amount of oil (8–12%) and is a good source of energy. Solvent extracted meal has low oil content (2–4%) and is high in protein (Table 20).

Due to the high fat content of the meal, it becomes rancid quickly which reduces its palatability. Antioxidants can be added to mitigate this.

Table 20: Nutrient content of copra (coconut meal)

DM	ME poultry	ME ruminants	DE pigs	CP	EE	CF	Ca	TP	AP	Lys	Met
%	Kcal/kg	Kcal/kg	Kcal/kg	%	%	%	%	%	%	%	%
90	1,500	3,150	3,200	23	8	13	0.3	0.6	0.2	0.5	0.35

DM: dry matter, CP: crude protein, CF: crude fibre, EE: oil content, Ca: Calcium, TP: total phosphorous, AP: available phosphorous, Lys: Lysine, Met: Methionine

Canola seed meal

Canola is a new variety of rapeseed which was developed using plant breeding techniques to reduce the toxic glucosinolate content. The canola seed contains approximately 40% oil and 17–26% protein (Table 21). A brown, free-flowing meal is obtained from the fat extraction of canola seeds. The meal contains a high concentration of protein (36–39%) and has a well-balanced amino acid profile.

Table 21: Nutrient content of canola seed meal

DM	ME poultry	ME ruminants	DE pigs	CP	EE	CF	Ca	TP	AP	Lys	Met
%	Kcal/kg	Kcal/kg	Kcal/kg	%	%	%	%	%	%	%	%
89	2500	2850	2800	38	3.5	12	0.9	1.2	0.4	1.8	0.8

DM: dry matter, CP: crude protein, CF: crude fibre, EE: oil content, Ca: Calcium, TP: total phosphorous, AP: available phosphorous, Lys: Lysine, Met: Methionine

Millfeed proteins

These protein supplements are obtained as by-products during the wet milling of maize, a process where the maize grain is soaked in water prior to milling. The main purpose of this process is to obtain starch for industrial use, although several by-products that are suitable as livestock feed are obtained. It should be noted that since these supplements are maize protein based, their quality is reduced due to low levels of lysine and methionine.

Maize germ meal

Maize germ meal is the product left after oil has been extracted using solvents from the germ. Depending on the extent of oil extraction, it can be a good energy supplement when oil is high or a good protein supplement when oil is low.

Maize gluten feed

Maize gluten feed is obtained when the bran portion from maize wet milling is mixed with the steepwater from the same process. The nutrient content depends on the relative proportions of bran, steep liquor, and other components. It has a high fibre content and is suitable for ruminant diets.

Maize gluten meal

Maize gluten meal is the principal protein of maize endosperm and consists mainly of zein and glutelin. The dried residue is obtained after the separation with bran followed by removal of starch and germ, during wet milling. It is normally available at two levels of protein (40% and 60%). It is low in lysine and tryptophan. Gluten meal is used in rations for all livestock, and due to high levels of xanthophylls is a good feed for poultry, especially due to deeper egg yolk and broiler skins yellow colour.

3.2.2 Protein supplements of animal origin

These protein supplements are derived from:

- Meat packaging and rendering operations
- Fish and fish processing

The quality of these protein supplements is high, as their amino acid composition is generally very similar to an animal's dietary needs.

Meat and bone meal

Meat and bone meal (MBM) is prepared from the wastes associated with slaughtering and rendering operations. These include carcass trimmings, condemned carcasses, inedible offal, and bones. Material such as hair, hoof, horn, hide, manure, or stomach contents are not included. The ash content is high (because of bone) at up to 28–36%. 8–11% of this is calcium, and 4–5% is phosphorous (Table 22).

It is not considered especially palatable and should be introduced into a ration gradually. The protein in meat and bone meal is degraded relatively slowly in the rumen and is therefore a good source of bypass protein. MBM is high in fat which increases its energy content.

Feeding MBM to cattle is thought to have been responsible for the spread of bovine spongiform encephalopathy (BSE, or mad cow disease). As such, MBM is no longer allowed in feed for ruminant animals.

Table 22: Nutrient content of meat and bone meal

DM	CP	EE	Ash	Ca	AP
%	%	%	%	%	%
94	46	10	30	11.8	5.6

DM: dry matter, CP: crude protein, EE: oil content, Ca: Calcium, AP: available phosphorous

Blood Meal

Whole blood meal is produced by spray drying fresh whole blood from animal processing plants at low temperatures. It is a high-quality source of protein and has an excellent amino acid profile.

Blood meal has a high lysine content and a CP content of 85%. Except for isoleucine, it is an excellent source of amino acids. Blood meal is low in calcium and phosphorous. It has low rumen degradability, and as such is a good source of bypass protein for ruminants. Blood meal, like meat and bone meal, is not allowed for inclusion in ruminant diets.

Fishmeal

Fishmeal is recognized as an excellent source of highly digestible quality protein, energy, minerals, and vitamins. Good quality fishmeal averages between 60–70% protein, 2–14% oil, and 6–12% moisture. The ash content ranges from 18–25%.

Fish meal is obtained from whole fish (mostly from species that store oil in their flesh and are not prized for their fillets e.g. herring, menhaden). The oil may or may not be extracted, resulting in high- and low-fat fish meals. Fish oils can oxidize easily due to unsaturation, and antioxidants must be added. The fish oil content is an important factor when considering poultry and swine diets, due to the fishy flavour it gives meat products.

Fish meal is an excellent source of proteins and essential amino acids, but poultry do not find it very palatable. It should be limited to 5–10% in poultry diets. High levels of fish meal will give an undesirable flavour to eggs, meat, and milk.

In East Africa, the Rastrineobola argentea species (known as 'omena' in Luo, 'dagaa' in Swahili, and 'mukene' in Luganda) forms the main source of fish meal. This fish contains on average 57% CP, 10% ash, 12% fat, and 6% lysine. Quality of the marketed meal can vary, especially due to adulteration with shells and sand by some suppliers. There is tendency to mix the omena with other types of fish which have more bone and less protein, increasing the ash content and lowering the protein content. It is therefore recommended that this fish meal is sampled and analysed for nutrient content prior to inclusion in rations.

Problems arising from salmonella contamination may be expected when fish are dried or ground unhygienically.

3.2.3 Non protein nitrogen sources

NPN includes any compounds that contain nitrogen but are not present in the polypeptide form of protein. Polypeptides can be identified through precipitation with trichloroacetic acid (TCA).

In practical feeding, NPN refers to added compounds containing NPN such as urea and excludes NPN which may be a natural constituent of feedstuffs. As the cheapest source of NPN, urea is used widely. Urea is hydrolysed rapidly in the rumen to yield ammonia which is utilized by rumen microbes to synthesize microbial proteins. NPN use is favoured in ruminant diets since in simple stomached animals, the urea is broken down in the lower gastrointestinal tract where the absorption of protein is limited.

Urea can be toxic if the ammonia release is faster than usage, which leads to ammonia absorption in the bloodstream. As such, it is recommended that urea should constitute no more than 1% of the total nitrogen in concentrates. In total mixed rations, urea should be restricted to no more than 0.5%.

3.3 Mineral and vitamin supplements and premixes

Minerals and vitamins make up a small portion of a ration and can be supplied by the basal ration. As a vital component of diets, supplementation is sometimes required for high producing animals. The level of supplementation of minerals depends on the mineral content of the basal diet. As much as possible, mineral requirements should be met from the basal diet. Requirements depend on species, age, type and level of production.

3.3.1 Minerals

The supplementation of both macro and micro minerals is required in most rations. Some common sources and their mineral contents is shown in Table 23. A proper balance of minerals is of concern as an excess of one mineral may interfere with the absorption or utilization of another or may cause toxicity. High levels of calcium, for example, will interfere with the utilization of phosphorous. High levels of salt (NaCl) can lead to poisoning.

The choice of a particular mineral supplement is dependent on:

- Cost (per unit of element)

- Chemical form of mineral which affects bioavailability
- Physical form of supplement (fineness of division and mixing)
- Freedom from any harmful impurities.

Most non-plant phosphorous sources are fairly well utilised. Approximately half of plant phosphorous is bound by phytic acid and not available to non-ruminants. During feed formulation, it is assumed that the Available Phosphorous (AP) is only half the Total Phosphorous (TP) and is available for non-ruminants, and 100% for ruminants, as phytin is metabolised by rumen micro-organisms.

Table 23: Common sources of macro minerals and their concentration (% DM)

	DM	CP	Ca	P	Na	Mg
Bone meal	97	13	30.70	12.80	5.70	0.33
Limestone	100	-	34.00	0.03	0.06	2.06
Calcium carbonate	97	-	39.40	-	0.01	0.05
Mono-Calcium Phosphate (MCP)	97	-	17	21	0.02	0.04
Dicalcium Phosphate (DCP)	98	-	22.00	19.30	0.10	0.60
Magnesium carbonate	98	-	-	-	-	30.81
Magnesium oxide	98	-	-	-	-	56.20
Sodium chloride	100	-	-	-	60.60	-

DM: dry matter, CP: crude Protein, Ca: Calcium, P: Phosphorous, Na: Sodium, Mg: Magnesium

3.3.2 Trace minerals and vitamins

Most trace minerals and vitamins are supplemented in rations in the form of commercial premixes. This can be defined as ready-mix preparation containing most of the ingredients that are required in trace amounts (minerals and vitamins) and are premixed based on the requirements not met by the basal ingredients. Common sources of trace minerals and vitamins in premixes are shown in Table 24.

Problems associated with commercial mineral premixes:

Commercial premixes are formulated and mixed by their manufacturers based on the assumption that some requirements are met by the basal diet. Premixes are age and species specific. The manufacturer supplies mixing instructions, but due to variations in basal ingredients, this may lead to excess or deficiency.

Table 24: Common sources of trace minerals and vitamins included in premixes

Element	Source
Potassium	Potassium chloride
Iron	Iron oxide (low availability), iron carbonate, iron sulphate
Copper	Copper sulphate, copper oxide
Manganese	Manganese oxide, manganese sulphate
Cobalt	Cobalt carbonate, cobalt sulphate
Iodine	Iodised salt, potassium iodide, potassium iodate, calcium periodate
Zinc	Zinc oxide, zinc sulphate
Selenium	Sodium selenate, sodium selenite
Molybdenum	Sodium molybdate
Sulphur	Ammonium sulphate, elemental sulphur in ruminants
Vitamin A	Retinyl acetate
Vitamin D3	Cholecalciferol
Vitamin E	Tocopherol acetate
Vitamin B1	Thiamine mononitrate

Element	Source
Vitamin B2	Riboflavin
Vitamin B3	Niacin–
Vitamin B12	Cyanocobalamin
Vitamin Biotin	Biotin
Vitamin Folic acid	Folic acid
Vitamin K3	Menadione Sodium

3.4 Feed additives

A feed additive is an ingredient added to the basic feed mix to fulfil a specific need and is typically used only in micro quantities. In practice, it is defined as a non-nutritive feed ingredient that can stimulate growth or other types of performance, improve the efficiency of feed utilization or be beneficial in some manner to the health or metabolism of the animal.

To decide whether to use a feed additive, the following criteria can be used:

- Cost:
- The main criteria is the increased income over the cost of the additive. If the increase in product equals the cost of the additive, there is no financial benefit of using it.

Safety:

- Whether the additive has a withdrawal or product discard period

Whether the additive can be used in combination with others in the same ration

Types of Additives

Additives that enhance market value

These are used to meet consumer preferences for products. Xanthophylls and carotenoids in poultry diets deepen the yellow colour of broiler skin and egg yolk, which is preferred by consumers.

Dehydrated alfalfa can be added to poultry diets as a source of xanthophylls for pigmentation.

Additives that physically aid digestion

Grit: most grinding (a reduction in size) of poultry feed occurs in the gizzard. The more thorough the grinding, the more surface area is presented for digestion and subsequent absorption. When coarse or fibrous feed is added to poultry feed, grit is added to supply additional surface area for grinding within the gizzard. This grit serves to break down ingested feathers which can sometimes lead to gizzard impaction.

Mashed feeds do not require the addition of grit. Examples of grit include oyster shells or gravel.

Antibiotics

Antibiotics are substances produced by living organisms and have bactericidal or bacteriostatic properties. Antibiotics improve the rate of gain and feed efficiency (growth promoters) via different mechanisms. The use of antibiotics should not replace proper management and sanitation. The use of antibiotics in livestock feeds is increasingly being prohibited due to increased cases of microbial antibiotic resistance.

Antibiotics are mostly included in chick starter, broiler starter, broiler grower, and creep feed.

Coccidiostats

Coccidiosis is a parasitic disease that affects the intestinal tract and is caused by coccidian protozoa. The disease is easily spread from one animal to another through contact with infected faeces or the ingestion of infected material. Coccidiostats are antiprotozoal agents and are of considerable importance to the poultry producer due to the close confines of modern poultry production.

Coccidiostats are mostly included in chick starter, broiler starter, growers mash, broiler grower, and broiler finisher

Antioxidants

Antioxidants prevent the oxidative rancidity of polyunsaturated fatty acids, as some high fat content raw materials used in the feed industry are prone to autoxidation. These include fat sources, fish products, and essential vitamins. Oxidation reactions are accelerated by high temperatures, light, and some trace minerals such as copper.

Buffers

Buffers are substances that are added to feed mixes to lessen or modulate pH changes that may occur in the rumen of cattle due to an excess production of acids. High concentrate rations and a sudden change from high roughage to high concentrate results in excess acid production in the rumen. This lowers the pH level of the rumen, changing the microbial populations in favour of more acidophilic ones). This leads to upsets, and buffers can prevent this by stabilizing rumen pH. Examples of buffers include sodium bicarbonate, magnesium oxide, sodium bentonite, sodium sesquicarbonate, and limestone.

Enzymes

These are added in feeds to help in the digestion non starch polysaccharides (NSP) present in cereals which are not digestible by digestive enzymes present in the animals alimentary canal. These NSPs contain ME which is released by the added enzymes.

Xylanases

The metabolizable energy of wheat is variable when fed to poultry, due to the presence of pentosans which are linked to other cell wall components. The main pentosan found in wheat is arabinoxylan. The xylanases enzymes have been added successfully to increase both the productivity and profitability of poultry and swine fed diets containing arabinoxylan-rich cereals and cereal by-products. The use of enzyme endo-(1,4)-D-xylanase in poultry diets hydrolyses the arabinoxylans to smaller fragments, losing the property of forming viscous solutions in the gastrointestinal tract.

Glucanase

The improved utilization of barley has been demonstrated by including microbial enzymes (cellulases or beta-glucanase) which results in a reduced viscosity of digesta due to the breakdown of the NSPs.

Cellulases

Cellulases can be included in diets of non-ruminant livestock to increase the digestion of fibrous materials (cellulose).

Proteases

Proteases improve the digestion of dietary protein present in feed.

Phytase

Phytase frees the phytin-bound phosphorus contained in plant-based feedstuffs. By breaking down the phytate structure, phosphorous and other minerals such as calcium and magnesium, as well as proteins and amino acids which have become bound to the phytate are released. The inclusion of phytase reduces the need for added phosphorous in livestock and poultry feeds, and reduces the level of excreted phosphorus through manure, reducing environmental pollution.

Ionophores

Ionophores are substances that are particularly effective at changing the metabolism within the rumen by altering rumen microflora to increase propionic acid production. They decrease acetic acid, methane and carbon dioxide production, and reduce the breakdown of natural protein by rumen bacteria. Increased propionic production improves performance of ruminants. Examples of ionophores include monesin and lasalosid.

Probiotics, prebiotics and synbiotics

Probiotics are substances that contain desirable gastrointestinal microbial cultures. These microbes are capable of exerting a beneficial effect either on growth of animal or an increased resistance to disease.

Prebiotics beneficially nourish the good bacteria already in the gut. While probiotics introduce good bacteria into the gut, prebiotics act as a fertilizer for the good bacteria that is already there.

Synbiotics are dietary supplements that combine probiotics and prebiotics in a form of synergism.

Acidifiers

These are organic acids that can control the growth of pathogenic microorganisms in the animal's digestive tract. They are an alternative to growth promoters.

Toxin binders

Toxin binders are substances which are added to animal feeds in small quantities to help neutralize harmful components such as mycotoxins or endotoxins within the gastrointestinal tract.

The most common of these are mycotoxin binders which trap mycotoxins, preventing them from entering the bloodstream where they can cause harm. Mycotoxin (aflatoxins most common) have increasingly become major contaminants of feed ingredients in developing countries and mycotoxins binders are common additives in feeds.

3.5 Recommended ingredient inclusion levels

Due to various factors discussed earlier, there are maximum recommended inclusion levels for various ingredients in rations of various types of livestock (Table 25).

Table 25. Recommended maximum inclusion levels of common feedstuffs in poultry and pig rations

Feedstuff (%)		Poultry			Pigs		
Starter		Broiler	Layer	Grower	Finisher	Sow	
Maize	Grain	70	70	70	30	30	30
	Bran	10	20	20	15	30	30
	Germ	10	20	20	15	30	30
	Gluten meal	5	10	10	10	15	15
	Gluten feed	5	10	10	10	15	15
Wheat	Grain	5	40	40	30	30	30
	Bran	5	15	15	5	30	30
	Pollard	10	20	20	15	30	30
Rice	Grain	40	70	70	40	70	70
	Paddy	5	10	10	5	10	10
	Polishings	10	20	20	15	30	30
	Bran	10	20	20	15	30	30
	Hulls	0	0	0	0	0	0
Barley	Grain	20	40	40	20	40	40
	Brewers' grain	5	10	10	10	20	20
Tubers	Cassava meal	40	40	40	40	40	40
	Dried potato	20	30	30	20	30	30
	Sweet potato	20	40	40	30	40	40
Cottonseed	Undecorticated	5	10	5	5	10	10
	Decorticated	10	15	5	5	15	15
Sunflower seed	Undecorticated	10	20	20	20	20	20
	Decorticated	10	20	20	20	20	20
Soybean	Cake	20	30	30	30	30	30
	Meal	20	30	30	30	30	30
Animal products	Blood meal	5	5	5	5	5	5
	Meat meal	10	10	10	10	10	10
	Meat and bone meal	5	5	5	5	5	5
	Fishmeal	10	5	5	10	5	5
Molasses	Molasses	5	5	5	5	5	5

3.6 Common anti-nutritional factors in feed ingredients

Some commonly used feed ingredients contain anti-nutritional factors which limit their utilization in the animal (Table 26). These can either be processed to remove or counter the effect including addition chemicals, enzymes or heat processing. Restriction of intake (inclusion level in ration) as shown above is the other option.

Table 26: Antinutritional factors in commonly used feed ingredients

<table>
<tr><th rowspan="2">Feedstuff</th><th rowspan="2">Factor</th><th rowspan="2">Class of animals affected</th><th rowspan="2">Effect on animal</th><th rowspan="2">Processing requirement</th><th colspan="2">Inclusion level (%)</th></tr>
<tr><th>Before processing</th><th>After processing</th></tr>
<tr><td>Wheat grain</td><td>Non starch polyscharrides</td><td>Poultry</td><td>Wet faeces</td><td>Restrict intake
Use enzymes</td><td>5–10 chicks
40 others</td><td></td></tr>
<tr><td rowspan="2">Sorghum</td><td rowspan="2">Tannins</td><td rowspan="2">Poultry, pigs</td><td rowspan="2">Reduced intake & performance</td><td rowspan="2">Use low tannin variety
Restrict intake</td><td>Low tannin</td><td>30</td></tr>
<tr><td>High tannin</td><td>5</td></tr>
<tr><td rowspan="4">Cottonseed cake/meals</td><td>Gossypol</td><td>Layers</td><td>Reduced intake
Discoloration of egg yolk</td><td rowspan="2">Low gossypol
Ferrous sulphate</td><td rowspan="4">5</td><td rowspan="4">10–15</td></tr>
<tr><td>Sterculic acid</td><td>Layers</td><td>Discoloration of egg white</td></tr>
<tr><td>Digestibility</td><td>Poultry and pigs</td><td rowspan="2"></td><td rowspan="2">Restrict intake</td></tr>
<tr><td>Imbalance in amino acids</td><td>Poultry and pigs</td></tr>
<tr><td>Fishmeal</td><td>Oil</td><td>Layers and broilers, turkeys</td><td>Low acceptance value of food product</td><td>Reduce oil content
Withdrawal period</td><td>10</td><td>10</td></tr>
</table>

Chapter 4: Quality control of raw materials

Good raw material quality management is based on the correct sampling, analysis, recording and understanding of laboratory results. Benefits include detecting variations in ingredient and feed quality, evaluating feedstuff suppliers, discounting substandard products, and explaining performance problems.

The following steps are necessary when determining the overall composition of raw materials:

- obtaining a representative sample for analysis
- converting the material into a form that permits analysis
- performing the analysis
- interpreting the data

The quality of an ingredient should be defined in a precise manner that is easily understood by all. A good quality material must be able to provide the stated nutrients and be free from deleterious substances that may affect feed utilization or the quality of the final food product derived from the fed animal.

4.1 Physical evaluation

Upon delivery, a physical and sensory evaluation of the raw feed materials should be carried out. The physical evaluation assesses qualities such as weight, texture, moisture, colour, smell, and whether the material has been contaminated. There is no need to take obviously physically spoiled raw material to the laboratory for chemical or biological analysis. A physical examination should check for the following:

Colour. Any change in the colour of feed ingredients (mostly grains) gives an indication of the dryness, storage conditions, presence of toxins, contamination, and possible use of insecticides or fungicides, which gives the feed a dull and dusty appearance.

Size. The size of the grains governs their energy value due to the proportional increase or decrease in the seed and its coat. A smaller grain has a lower starch content thus low metabolizable energy value.

Contaminants. The presence of contaminants such as other grains, husks, broken grains, weed seeds, infested seeds, rodent droppings and dust should be checked for. Husk and sand are common contaminants. Winnowing is the best method to detect husk in the feedstuff. Sieving can be undertaken to differentiate contaminants based on particle size.

Sound upon pouring. When poured, dry grains will produce a sound similar to spilling coins.

Weight. The material should be weighed to confirm that the delivery is as indicated/ordered.

Texture. Feeling the raw material will indicate its dryness, moisture content and texture, as well as whether it is finely or coarsely ground, or dusty.

4.2 Wet laboratory analysis

4.2.1 Sample preparation

Quality analysis of a compounded feed or raw material is only as good as the sample used. Poor sampling will give erroneous results. As such, the most important precondition when analysing feedstuffs and mixed feeds is the sampling procedure.

The following principles should be observed:

- The sample taken must be representative of the entire lot.
- Samples should be taken randomly from several different points of the lot, mixed to produce a collective sample, and divided into several representative laboratory samples for analysis.
- Samples need to be stored to ensure that the ingredients will not be altered by temperature, oxygen, sunlight and other factors before analysis.

4.2.2 Analysis

Proximate Analysis: This is a basic analysis of a raw material or mixed feed which determines its nutrient values and breaks it down into six categories based on chemical analysis: moisture, ash, CP, crude lipid, crude fibre, and nitrogen-free extracts (mostly digestible carbohydrates such as sugars and starch).

Moisture is the amount of water in a sample. The sample is oven dried at 105°C for 12 hours. The weight loss by the sample is determined and is equivalent to the amount of moisture. Moisture content is important, as high moisture content will lead to faster spoilage (moulds), high shrinkage during storage, and lower nutrient content as water does not contain nutrients. The remaining portion after removal of moisture is the dry matter content.

Ash represents the inorganic portion of a feed and consists of the residue after ashing. Crude ash is determined by burning a sample at 600°C for 2 hours. Ashing removes the organic matter which constitutes the carbohydrates, fats, and proteins from the sample. The remaining sample represents the portion that contains minerals (both soluble and available to the animal, and insoluble such as silica in form of sand). Mineral source ingredients, e.g. bone meal, are particularly high in ash.

Ash content can be used to determine the degree to which materials have been adulterated (e.g. with sand or shells) and the amount of bone in fish meal.

To determine the portion of the ash fraction that is soluble (and therefore available to the animal), the sample can be analysed for another fraction known as acid insoluble ash (AIA), which is an indicator of silica content.

CP is quantified through the determination of total nitrogen in the sample. The main drawback to this method is the assumption that all nitrogen contained in a sample is from protein.

NPN, which is only available to ruminants, is included in the CP measure. It is found in both plant- and animal-based ingredients but can be added, for example, from urea. CP values should therefore be interpreted with care, especially for ingredients that are used in feed for non-ruminants.

Unlike energy where only quantity is important, the quantity and quality of the protein in an ingredient is important. The true quality of protein (for non-ruminants) in an ingredient can only be determined through the analysis of individual amino acids. High amounts of essential amino acids in an ingredient, is an indicator of high quality.

Crude fibre is primarily composed of fibrous (indigestible) carbohydrate found in plant-based ingredients, e.g. cellulose, hemicellulose, and lignin. Crude fibre is an indicator of relative indigestibility and bulkiness of an ingredient or feed. Ruminant animals can mostly utilize the fibre but not the lignin, so the measure is more important for non-ruminant feeds.

Crude fat (ether extract). Fats contain more energy per unit weight than carbohydrates and protein, so the higher the fat content, the higher the energy content. "Crude fat" indicates that some of the fat fraction may be in a form that is not utilizable by the animal.

Nitrogen-free extract is the percentage of remaining content, i.e. 100 – (% moisture + % ash + % crude fibre + % CP + % crude fat). It consists mainly of sugars and starches. A high **nitrogen-free extract** indicates more available carbohydrates both for ruminants and non-ruminants.

Mineral analysis. Determination of the mineral content of ingredients is important to ensure that the required amounts are included in the final ration. Both macro minerals (calcium, phosphorus, etc.) and micro minerals can analysed in the laboratory using an atomic absorption spectrophotometer, flame photometer or colorimetric methods (using spectrophotometer). The results are expressed in g/kg for macro minerals and μg/kg (ppm) for micro minerals.

4.2.3 Dry laboratory analysis

Dry laboratory analysis uses near-infrared spectroscopy (NIRS) technology to determine the nutrient content of a feed using light reflection rather than chemistry. Dry analysis gives fast results with minimal sample preparation. However, it is recommended only for common feeds where calibration has been undertaken. It is not recommended for minerals.

4.3 Interpretation of laboratory results

Concentration of nutrients can be expressed on either an 'as is' or dry matter basis. For an 'as is' basis, the nutrient content is given for the sample as it was delivered to the laboratory. For 'a dry matter basis', the nutrient content is the concentration of the nutrient in the sample when all the moisture has been removed. Nutrient concentrations expressed on an 'as is' basis are less than those expressed on a dry matter basis. It is therefore important to note on what basis nutrients are expressed prior to using the results for feed formulation.

CP, fibre, fat, and macro mineral content are usually expressed as percentages (either 'as is' or dry matter). Micro minerals are usually expressed as parts per million or (mg/kg).

Chapter 5: Nutrient requirements of livestock at different levels of production

Feeding standards are comprehensive estimates of animal nutritional needs made by bodies charged with standardization. In East African region, these bodies include the Kenya Bureau of Standards, the Uganda National Bureau of Standards, the Tanzania Bureau of Standards, the Rwanda Standards Board, the South Sudan Bureau of Standards and Burundi Bureau of Standards and Quality Control.

Variations in performance of livestock fed using these standards are to be expected due to the different environmental and genetic factors involved. Standards indicate minimal requirements only. Feed formulators need only use them as guides, they may exceed them.

5.1 Sources of variability during feed mixing

Even with standardised feeds, the following factors will lead to some variability in livestock performance:

Mixing of feed ingredients is necessary to make a complete feed. The nutrient composition of the feed's ingredients is determined from samples that have inherent variability. The variability is increased when the actual ingredients to be mixed are not analysed and nutrient content is estimated from textbook values.

During mixing, the mixer is itself subject to variability.

The mixed feed is fed to animals of variable genetic feed conversion abilities, and animals are fed under variable environmental conditions in the farm. This source of variation may not be attributed to the feed manufacturer.

When a complete feed mixed using the standards is fed to a group of selected uniform animals, e.g. commercial chickens produced through highly inbred lines and in a uniform environment, responses are more uniform and predictable and can be fairly assessed

5.2 Livestock feed standards

The standards (Table 27) for the following feeds are guidelines and the feed producer should obtain the most up to date standards from the respective local standards body.

Table 27: Feed standards for poultry, pigs and cattle

Poultry	**Chick starter**	**Grower mash**	**Layer mash**	**Broiler starter**	**Broiler finisher**
Nutrient					
Metabolised energy (kcal/kg) (min.)	3,000	2,550	2,750	3,000	3,000
Crude protein (%) (min.)	18	14	16	22	18
Crude fibre (%) (max.)	6	6	6	6	6
Crude fat (%) (max.)	6	6	6	6	6
Calcium (%) (min.)	1	1	3.4	1	1
A. P (%) (min.)	0.4	0.35	0.4	0.45	0.45
Lysine (%) (min.)	1.1	0.6	0.75	1.2	1
Methionine (%) (min.)	0.44	0.3	0.38	0.46	0.4
Pigs	Creep feed	Sow & weaner	Pig finisher		
Nutrient					
D Energy (mcal/kg)	3.4	3.2	3.0		
Crude protein (%)	18	16	14		
Crude fibre (%) (max)	6	6	6		
Crude fat (%)	6	6	6		
Calcium (%)	1	0.75	0.6		
Phosphorus (%)	0.75	0.6	0.4		
Lysine (%)	0.9	0.8	0.6		
Methionine (%)	0.55	0.41	0.32		
Cattle*	Dairy calves	Heifers	Mature dairy cows		
Nutrient					
Moisture (%) (max.)	12	12	12		
Crude protein (%) (min.)	18	14–16	14–16		
Non-protein nitrogen (%) (max.)	0	2	2		
Crude fibre (%) (max.	8	12	12		
Crude fat (% (max.)	3–8	3–6	3–6		
Calcium (%) (min.)	0.7	0.7	0.7		
Phosphorus (%) (min.)	0.5	0.5	0.5		
Common salt (%)	0.5–0.6	0.5–0.6	0.5–0.6		

* For cattle, the standards are for concentrate supplements. For Total mixed rations, the standards depend on milk production

Chapter 6: Feed formulation

6.1 What is feed formulation

Feed formulation involves the quantification of feed ingredients mixed to supply all the nutritional requirements for the maintenance and desired production of a specified animal at the lowest cost. The formulator develops a nutritionally adequate ration that is consumed in sufficient amounts to provide the desired level of production.

Prior to the initiation of a feed formulation, the following information is required:

Nutrient requirements of the animal. This information is obtained from animal feed standards which have been developed by legally mandated institutions in different countries.

During formulation, it may not be necessary to consider micronutrients (trace elements and vitamins) as these can be supplied through premixes. The macro nutrients (energy, protein), amino acids and macro minerals are considered.

Availability of feedstuffs. For homemade rations, locally available material should be used as much as possible. For commercial feeds, a wider range can be used.

Nutrient content of each feedstuff. This should be obtained through i.) direct laboratory analysis, ii.) analysis results from reliable suppliers, or iii.) feedstuffs that have a relatively uniform composition (e.g. whole cereals) from published sources (textbook values). Published values however can be misleading, especially for by-products, as local processing may affect outcomes. Whenever possible, laboratory analysis of by-product-based ingredients should be made for a more accurate formulation.

Cost of ingredients delivered to the farm/plant. Cost considerations should be based on the value of the nutrients being supplied by an ingredient i.e. following the concept of purchasing nutrients, not ingredients. The quality of the nutrient should be considered (e.g. proteins in terms of amino acid quality).

Limitations of inclusion for each ingredient and livestock species. The use of fish meal for example as broiler feed can taint the meat. Feeding CSC to chicken layers causes egg spoilage.

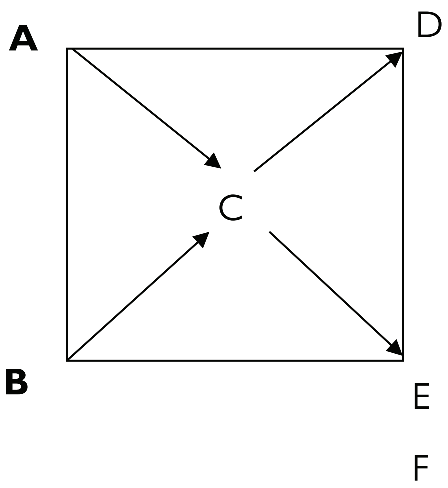
During feed formulation, it should be noted that i.) simple nutrient needs can be met adequately by simple feed formulas (complexity does not necessarily improve performance); ii.) an individual feedstuff will rarely supply all nutrient needs; iii.) trace minerals and vitamins are added as premixes (as per manufacturer recommendations); and iv.) feed additives are added as per supplier instructions.

6.2 Formulation techniques

6.2.1 Pearson square method

The Pearson square method (Figure 9) is designed for simple rations. It balances one nutrient at a time from two feedstuffs. Its advantage is that it serves as an indicator of the best possible mixture of two feedstuffs or feedstuff mixtures.

Figure 9: The outlay of a Pearson square method.



Where:

A = nutrient concentration of first feedstuff

B = nutrient concentration of second feedstuff

C = nutrient level required in ration

D = required proportion (parts) of first ingredient in diet

E = required proportion (parts) of second ingredient in diet

F = Total of the different parts (D+E) making the ration

Method

1. Obtain D by subtracting C from B (or B from C) (always subtract the lesser value from the greater on the diagonal to ensure a positive answer)

2. Obtain E by subtracting C from A (or A from C) (always subtract the lesser value from the greater on the diagonal).

3. Sum D and E to obtain F (D + E = F). For ease of mixing these (D and E) are often recalculated in percentage form to mix 100kg.

Example: Make a ration with 18% CP using CSC (40% CP) and maize (10% CP).

1. C – B = 18 – 10 = 8 (D) (parts of CSC required)

2. A – C = 40 – 10 = 30 (E) (parts of maize meal required)

CSC 40% (A) 8 parts CSC (D)

18% (C)

Maize (10%) (B) 22 parts maize (E)
Total **30 parts (F)**

Answer: to achieve a mix with 18% CP, mix 8 parts CSC and 22 parts maize.

3. D + E = 8 + 22 = 30. Expressed as a percentage (per 100 kg feed):

8/30 * 100 = 26.7% CSC

22/30 * 100 = 73.3% maize

To confirm that the ration contains 18% CP:

CSC: 26.7*(40/100) = 10.7

maize: 73.3 * (10/100) = 7.3

Total = 10.7+7.3 = 18kg CP in 100kg diet (18%)

Notes:

The lesser value is subtracted from the larger within the diagonal so that no negative value is obtained.

It is not possible to produce a ration with a higher or lower nutrient content than the ingredients. From the above example, the CP of the resulting mixture cannot be higher than 40% or lower than 10%. This stresses the principle that "you can never make a better feed than your raw materials can make".

From the above, one ingredient must have a higher nutrient content than desired nutrient concentration in the ration and the other must be lower.

Whenever there is a conflict between the standard and the nutrient content of the feedstuffs (i.e. the available feedstuffs are not to meet the required the standard), either the standard must be lowered, or other feedstuffs must be obtained. The acceptable alternative is to obtain better quality feedstuffs to meet the standard.

6.2.2 Pearson square with three or more feed resources

Example: formulate a ration containing 15% CP from a mixture that is three parts CSC and one part meat meal (CSC/MM) and maize. Assume the CSC contains 40% CP, meat meal contains 55% CP and maize contains 10% CP.

Step 1: Calculate the protein content of the CSC and meat meal mixture:

Contribution by CSC: 3/4 (75%) * 40 CP% = 30 CP%

Contribution by meat meal: ¼ (25%) * 55 CP% = 13.75 CP%

Total CP in mix = 43.75%

The Pearson square can then be used to mix the maize and the CSC/meat meal mixture. The meat meal + CSC mixture is treated as one ingredient with a CP content of 43.75%.

Step 2: Use the Pearson square method to calculate the ration mix (how many parts for each other the ingredients) given that the CSC/meat meal mix is 43.75% CP and maize has 10%CP.

CSC/MM 43.75% 5 parts CSC:MM

15%(desired)

Maize (10%) <u>28.75 parts Maize</u>

Total **33.75 parts**

To achieve a mix with15% CP, mix five parts CSC/MM and 28.75 parts maize.

When this is expressed as a percentage (100 kg feed):

5/33.75 * 100 = 14.82% CSM/MM

28.75/33.75*100 = 85.18% Maize

To confirm that the ration contains 15% CP:

CSC:MM 14.82*43.75/100 = 6.48kg CP

Maize 85.18*10/100 = 8.52kg CP

Total **15kg CP/100kg feed (15%CP)**

The 14.82% mix is then divided into 75% (3/4) CSC and 25% (1/4) MM

CSC: 11.11%, MM: 3.71%

The final mix will therefore be:

CSC:11.11%

Meat meal: 3.71%

Maize: 85.18%

6.2.3 Algebraic equations

Algebraic equations may be generated for nutrient concentration and their solutions used in finding proportions of mixing the feedstuffs into a diet.

Two feedstuffs, maize (10% CP) and soya meal (50% CP), are combined to make a mix for starter pigs at 20% CP.

Two equations can be developed.

Let the amount of maize be X and the amount of soya meal be Y

In making 100 kg (or a 100% mixture), X kg of maize and Y kg of soya are to be used.

Therefore: **X + Y = 100**

The concentrations of protein being as above, to make a diet that is 20% (or 20 kg of protein in 100 kg of mixture) a second equation can be generated, reflecting the ingredients' CP content:

0.1X + 0.5Y = 20

The set of simultaneous equation is therefore:

i.) X + Y = 100 (the total amount of mixture)

ii.) 0.1X + 0.5Y = 20 (the total amount of CP)

iii.) X + 5Y = 200 which is (ii x 10)

4Y=100 (iii-i)

Y=25

X=75

The **unique solutions** are X=75 and Y= 25.

6.2.4 Substitution method

This is the process of substituting an amount of one ingredient by another ingredient in a feed formula.

Step 1

Original formula

Ingredient	amount (kg)	CP%	CP contribution (kg)
Rhodes hay	50	8	4
Maize grain	35	10	3.5
CSC	15	40	6
	100		13.5

Step 2

Increase the CP content to 15% by substituting maize with CSC

Although a trial and error method can be used, a substitution method is better.

Add 1 kg CSC (0.400 kg protein will be added)

Remove 1 kg maize (0.100 kg protein will be removed)

Change in CP = 0.300 kg

Step 3

The expected increase is from 13.5 kg to 15 kg. 1.5 kg of protein is therefore required in the 100 kg mix.

Step 4

If the ingredients are substituted kg for kg, the increase is 300g of protein.

Therefore

1.5 kg of protein divided by 0.300 kg = 5 kg of CSC needed to substitute 5 kg of maize.

Step 5

New formula

Ingredient	amount (kg)	CP%	CP contribution (kg)
Rhodes hay	50	8	4
Maize grain	30	10	3
CSC	20	40	8
	100		15

6.2.5 Trial and error method

This method involves continuously adjusting the ratios of ingredients until the right mix of ingredients that meets the standards is achieved. It is best achieved using computer-based software (e.g. Excel spreadsheets) where the ratios of the ingredients are continuously adjusted based on the outcome of the previous ratio to achieve the final objective. Table 28 is an example of a spreadsheet to balance a ration for layer where three trials are carried out.

Table 28: Example of trial error calculations made using a spreadsheet for layer feed

Ingredient	Ingredient contribution			Nutrient content of ingredients/feed			
	T1*	T2*	T3*	ME (Kcal/kg)	CP (%)	Ca (%)	Available P (%)
Maize grain, ground	40	55	62	3,300	10.0	0.03	0.15
Pollard	30	20	15	1,800	16	0.13	0.45
CSC	15	13	6	2,000	35	0.18	0.33
Fish meal	8	5	8	3,000	55	2.0	1.5
Limestone	5	6	7	0	0	33	0
Dicalcium phosphate(DCP)	2	1	2	0	0	23	18
Total	100	100	100				
T1*				2,400	18.45	2.348	0.7245
T2*				2,585	16	2.375	0.4704
T3*				2,676	15.1	2.978	0.6603
Requirement				2,750	16.0	3.0	0.45

*T1, T2 and T3 are the different trial and error ingredient combinations.

In this example, the formulator through experience comes up with the first combination of ingredients (T1) for a layer ration and calculates the nutrient contribution of the formulation and compares with the requirement.

The calculation for the nutrient contribution for each of the materials is calculated as shown for ME and CP as an example:

ME per kg of feed= maize will contribute 40/100*3300, pollard=30/100*1800, CSC =15/100*2000, fish meal =8/100*3000= **2,400Kcal/kg feed** (Note Limestone and DCP do not contribute to ME)

CP%= maize will contribute 40/100*10, pollard=30/100*16, CSC =15/100*35, fish meal =8/100*55= **18.45%CP**

From the shortcomings, the formulator, from knowledge of ingredients, subtracts amount of ingredient to reduce the nutrients in excess or adds to increase deficient nutrients

T1: represents a layer feed with excess protein and phosphorus but with low energy and calcium.

T2: maize is added to improve energy and the protein sources reduced. To improve Ca, limestone is increased. Note that any increase of one ingredient must be accompanied by a decrease on another as the total is always 100.

T2 is an improvement of T1 and involves increasing the content of energy and calcium sources (i.e. maize and limestone).

However, T2 is still low in energy and has been improved in T3.

T3 does not exactly balance due to limitation of ingredients used. In the trial and error method, it is difficult to get an exact balance, but one should attempt to get as close as possible to the requirement.

6.2.6 Least-cost computerized feed formulation

This computerised method determines the least-cost combination of ingredients using a series of linear equations. A least-cost formulation satisfies both scientific standards (nutrient requirements and limitations) and practical (e.g. ingredient availability) at the lowest possible cost.

Feeding standards that are used in the formulation are the minimum therefore the final mix should have at least the stated amounts of nutrients. The method allows flexibility in amount (e.g. if protein required is 16%, it allows amounts slightly higher than 16%) unlike other simpler methods which only handle equalities (exact amounts).

In the example given in Table 13 below, a ration for laying chicken is to be formulated to meet the following specifications:

Ingredients available: whole maize, Pollard, CSC, Fish Meal, Limestone, Dicalcium phosphate, Salt, Premix given in row 1 of Table 29.

Cost: the cost of the above ingredients per kg is given in row 2 of the table.

Amount of each ingredient in the ration: these are to be calculated and are abbreviated in row 3 of table as?

The nutrient concentration (ME, CP, Ca, AP) for each of the ingredients is given in rows 4–7.

Limitations: this indicates limitations due to acceptability by animal, availability, anti-nutritional factors, and manufacturer's recommendations. In this example, maize is limited to maximum 45% due to availability, pollard is capped to minimum of 30% since it is readily available, Fishmeal at maximum 10% due to the fishy smell, salt at 0.5% and premix at 0.25% as recommended.

Type of restriction (these restrictions are required by the software to calculate the ingredient ratios).

Cost: since the formulation is least cost; the restriction is that the final formulation should cost the minimum possible price (while meeting other conditions).

Weight: the total weight of ingredients equals 100

ME (kcal/kg): this should be a minimum of 2750 as per standard but can be slightly higher.

CP%: this should be a minimum of 16% as per standard but can be slightly higher.

Ca (%): this should be a minimum of 3% as per standard but can be slightly higher.

AP (%): this should be a minimum of 0.45 as per standard but can be slightly higher.

The matrix can then be used by the least cost formulation software to formulate a least cost ration.

aThe prices indicated are in USD and should be replaced with the local price.

Table 29: Example of matrix for a least cost formulation

Specifications	Whole Maize	Pollard	Cottonseed cake	Fish meal	Limestone	Dicalcium phosphate	Salt	Premix	Type of restriction	Restrictions
Cost, USD/kg[a]	0.35	0.25	0.45	1.30	0.07	0.70	0.10	2.50		Minimize
Weight, kg	?	?	?	?	?	?	?	?	=	100
ME, Kcal/kg	3,300	1,800	2,000	3,000	0	0	0	0	≥	2,750
CP, %	10.0	16	35	55	0	0	0	0	≥	16
Ca, %	0.03	0.13	0.18	2.0	33	23	0	0	≥	3
Available P, %	0.15	0.45	0.33	1.5	0	18	0	0	≥	0.45
Limits on ingredients										
Max (%)	45			10						
Min (%)		30								
Exact (%)							0.5	0.25		

[a]The prices indicated are in USD and should be replaced with the local price.

Limitations of computer use in ration formulation

The use of computer software for feed formulation is standard practice. Several types of software are available in the market, mostly at some cost ranging from cheaper versions for small-scale feed manufacturers and home-based formulations (fewer functions) to expensive professional versions. Microsoft Excel-based software (Solver function) is another option. Computer analysis allows rapid formulation of rations that meet nutrient specifications at minimal cost. However, the formula produced is only as reliable as the input data: computers are aids to feed formulation, not feed formulators. Wrong data inputs will produce incorrect formula. The nutritionist must make the decision as to the suitability of the resultant mixture.

Chapter 7: Feed processing: milling, mixing and packaging

7.1 Reasons for processing feeds

The main purpose of correctly processing feeds is to prepare it for better utilization. This may be through improving handling, neutralizing anti-nutritional factors, increased intake and improved digestibility. These are achieved through some of the following ways.

Increase efficiency of:

Handling: Pelleting to reduce wastage and dustiness and ease feed flow

Utilization: Palatability: mixing urea with grains

Digestibility: increased surface area for enzymatic activity, altered molecular enhance digestion, increased rate of gain and efficiency.

Change density of feed:

Increased bulk of concentrate diets: reduced digestive disorders

Reduce bulk in roughage-based diets (increased intake)

Increase shelf life for preservation (e.g. drying)

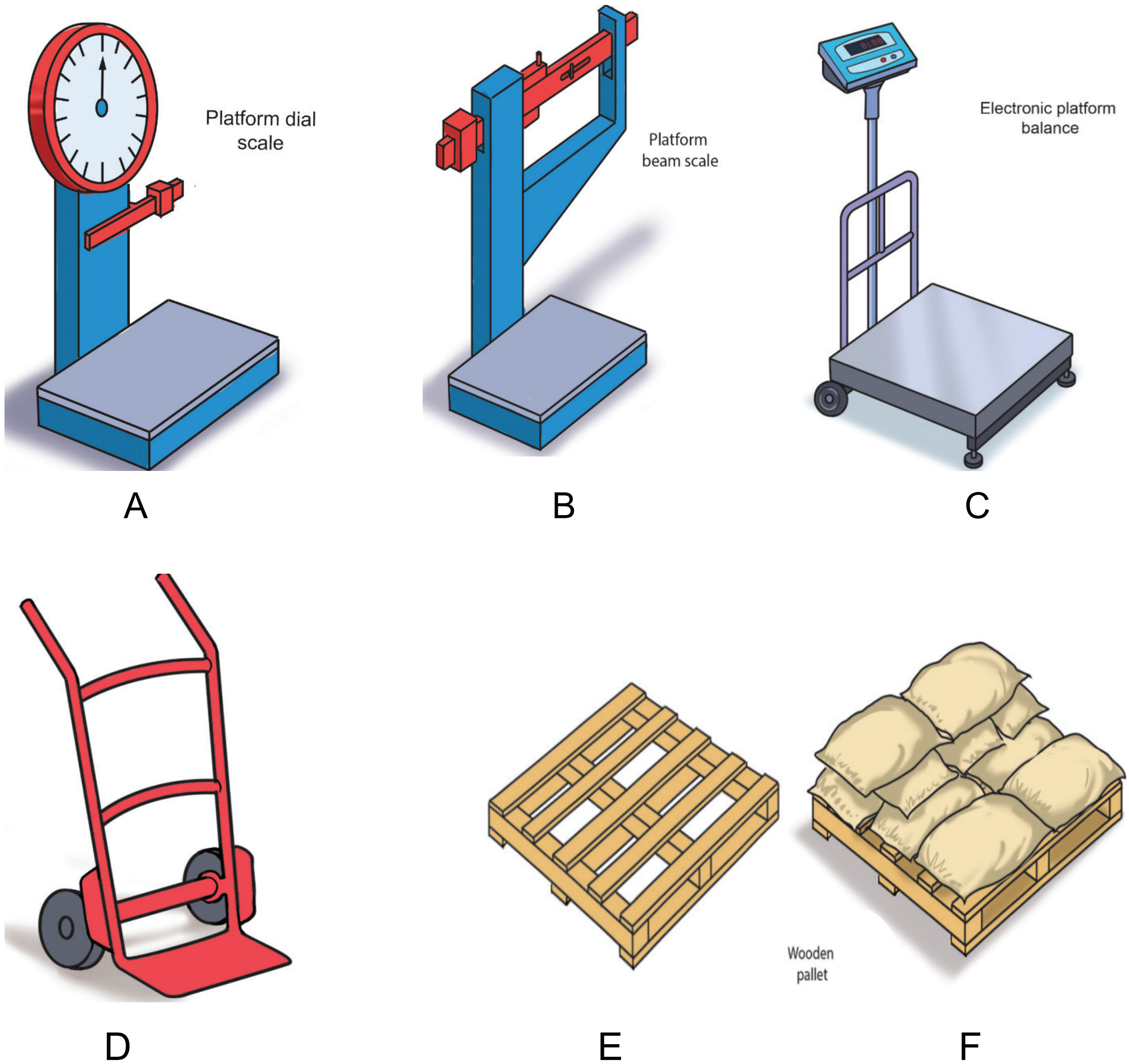
7.2 Raw material sourcing and storage

Once the materials have been sourced and delivered to the feed mixing plant, they should be weighed, labelled and stored. Weighing should be undertaken by randomly selecting bags during offloading using a platform scale. Examples of types of weighing scales and storage equipment are shown in Figure 10.

Since the price of feeds ingredients varies, storage is necessary to take advantage of buying during times when particular ingredients are cheap (e.g. maize during harvesting season). In small-scale settings, feed bags should be placed on pallets a few inches from the floor. When determining space requirements, the bulkiness (weight per volume) of the materials must be considered.

Raw materials must be stored in waterproofed and well-ventilated areas protected against insects and vermin infestation.

Figure 10: Weighing and storage equipment in a feed mixing plant.



(A: platform dial scale, B: platform bream scale, C; digital platform scale, D: sack barrow, E: wooden pallet, F: correctly loaded pallet).

Adapted from Parr W.H. (1988).

7.3 Types of mixed feeds

Mash

Feed mash is a blend of several feed ingredients in the correct proportions to meet nutritional requirements. Ground to a small size and mixed so that it cannot easily separate, it is the simplest solid feed form that can be manufactured. Each mouthful provides a well-balanced diet.

Pellets

Pellets consist of mash that is mechanically pressed into hard, dry pellets, sometimes referred to as artificial grains, in a process that involves steam injection (moisture and heat) and mechanical pressure.

Compared to mash, the feeding of pellets is generally accepted to improve livestock performance. This is attributed to reduced feed wastage and improved feed conversion efficiency (FCE).

The positive effects of pelleting are well documented: higher feed density, no feed ingredient separation, better bacteriological quality, easier ingestion, improved livestock growth and FCE.

Crumble

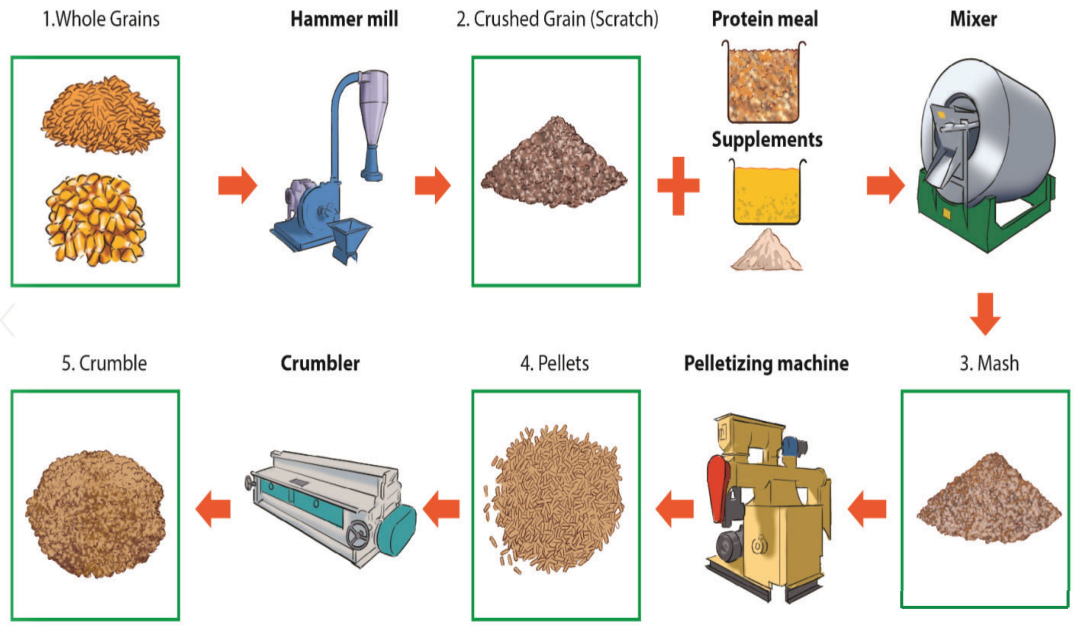
Crumble is made from whole pellets that are crushed to a consistency coarser than mash. Recently this form of feed has become popular in poultry production due to its convenience of feeding. Very fine crumble can only be achieved with high quality pellets. Chickens tend to prefer crumble over larger pellets.

The process of producing the three types of feed (mash, pellets and crumbs) is shown in Figure 11 below.

Flakes

Flaking is another way to increase the nutritional value of whole grains fed to cattle and other ruminants by improving grain digestibility. Steaming the grain prior to flaking has been shown to further enhance its nutritional value. Grain with a higher moisture content (absorbed during steaming) creates a flatter rolled flake and the starch is gelatinized, which makes the starch more available to the animal. The cereal (mostly barley) flakes can be fed wet if rolling is on farm or are dried prior to packaging for sale.

Figure 11: Schematic diagram of the preparation of mash, pellets and crumbs.



Adapted from Patch to Table (2021).

7.4 Feed milling and mixing

Raw materials are milled to reduce their size to facilitate mixing. To obtain a uniform mixture, raw materials should be of a similar size as possible.

Size reduction can be achieved through grinding, which involves reducing particle size through crushing, breaking and sieving to separate particles on the basis of size. More finely-ground feed improves intake and digestibility, but affects the feeds' compaction, i.e. it produces more dust and has a higher shrinkage and wastage rate. Finely ground material is more vulnerable to wind loss, may be less palatable, and may clog self-feeders. The desired fineness of the ground material will depend on the livestock to be fed e.g. poultry feed should be more finely ground than cattle or pig feed. If the mixed product requires pelleting, the raw materials should be more finely ground than the equivalent feed as meal. Recommended sizes of grind for poultry and pig mash feeds are those produced by 2 mm to 6 mm sieves.

During grinding, bulky materials (e.g. maize grain) grind more easily that the low bulk materials (e.g. bran). Premixing these materials prior to grinding is more efficient.

7.4.1 Milling equipment

Hammer mills consist of a rotating flywheel rotor with swing-type hammers in a chamber where a perforated screen determines the final particle size. The hammer mill can grind roughage, maize, small grains, and mixtures, but lacks uniformity of grind, although it can produce fine particles.

Table 30 gives the recommended screen size of milling for different types of livestock.

Table 30: Recommended screen size for milling for different types of livestock

Livestock type	Screen size (mm)
Cattle	6.5–12.5
Sheep	3.0–12.5
Finishing pigs	2.5–4.0
Young pigs	1.5–3.0
Poultry	2.0–4.0

The output rate of a hammer mill depends on:

Screen size: larger screen size has higher output

Screen area: larger screen area has higher output

Hammer age: newer hammers grind better

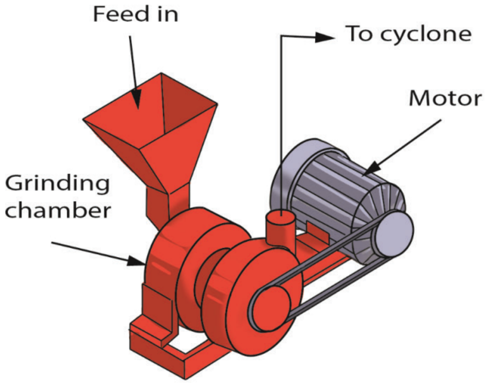
Type of material: softer grains grind faster

Moisture content: low moisture (13–14%) grinds faster

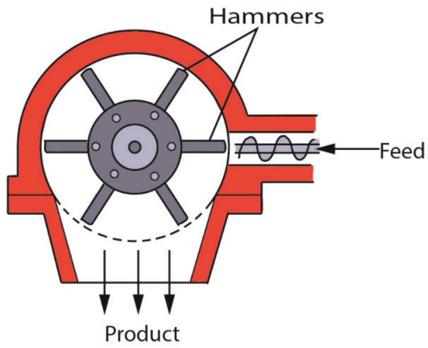
Mill power: higher power has greater output

The different parts of the hammer mill are shown in Figure 12.

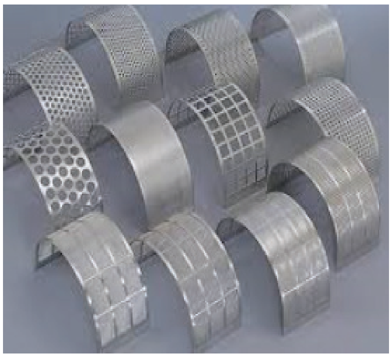
Figure 12: Different parts of hammer mill.



A



B



C

A: complete hammer mill and motor, B: section showing the hammers and grinding chamber, C: different sizes of sieves

7.4.2 Feed mixing

Feed mixing is the agitation of two or more materials to facilitate combination. Mixing starts with weighing raw materials, the accuracy of which is one the most important operations in feed manufacturing. The point at which weighing occurs depends upon the design of the mill.

During weighing, greater accuracy should be taken for raw materials which are required in small quantities as errors during weighing may affect animal performance, e.g. the omission of 5 kg of wheat pollard in a 300 kg mix will have less of an impact than the omission of 0.5 kg of premix in 2.5 kg. More accurate scales should be purchased for micro ingredients.

Mixer types

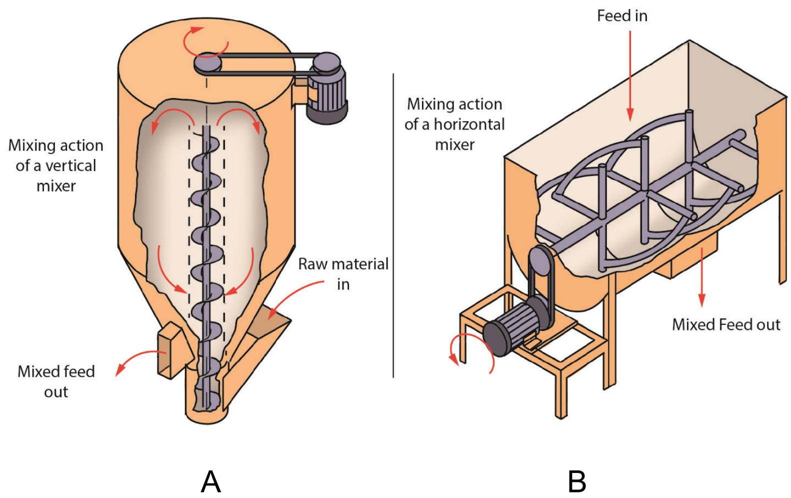
Small-scale feed manufacturers normally use batch mixers. Individual ingredients are ground, weighed, and fed into a mixer in batches depending on capacity. After mixing, the batch is off-loaded prior to loading a new batch. If the mixer and hammer mill are connected using conveying equipment, the milled ingredients can be loaded directly to mixer saving labour and time. A mixer should have a high capacity in order to minimize the number of batches. As opposed to continuous mixers (automated in large-scale manufacturing), batch mixers require several operators to be present at any one time to load and offload.

Vertical mixers consist of a vertical cylinder (1.5 m in diameter) normally equipped with a central auger driven by a motor from the top or bottom (Figure 13A).

The augers lift the feed to the top of the mixer and a conical loading hopper is usually located at the bottom of the cylinder. After mixing for 10–15 minutes (after the loading of the final ingredient), the mixture is discharged into a bag or conveyed by auger or bucket elevator to a storage bin. During emptying, the mixer should be running to ensure minimal retention of mix in the hopper. Vertical mixers are not effective in distributing liquids in a mixture due to their slow-running action. Liquids tend to form balls coated with fine particulate material.

Vertical mixers require low initial costs and low power requirements but have a longer mixing time. They save on space, but disadvantages include poor liquid mixing, gravitation of heavy particles, poor blend uniformity, and incomplete emptying.

Figure 13: Types of mixers. A: vertical mixer, B: horizontal mixer.

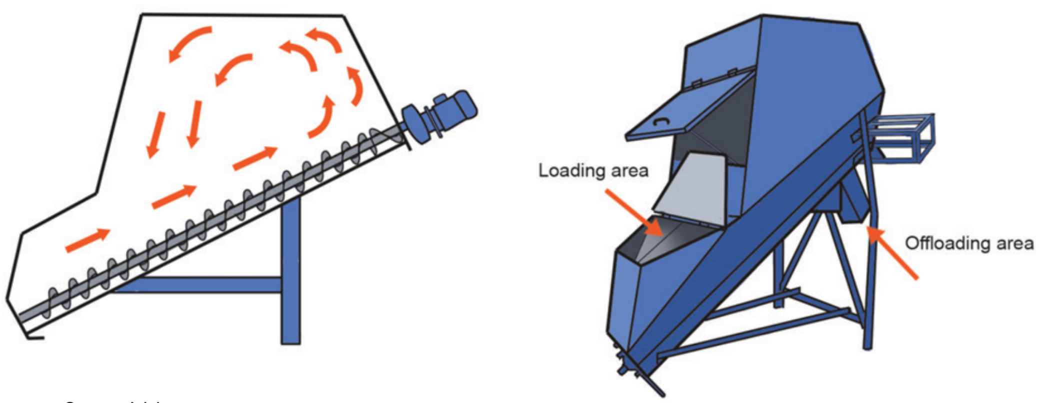


Adapted from Parr W.H. (1988).

Horizontal mixers are U-shaped containers with a horizontal shaft holding paddle agitators (Figure 13B). The mixer is suitable for blending liquids and the mixing time is about is shorter (5–10minutes) compared to the vertical. Horizontal mixers can mix heavy and sticky material (e.g. oils or molasses), are easy to empty, and provide more accurate mixing over a short time. Their disadvantage is in their higher purchase price, consumption of power, and difficulty in being loaded.

Inclined auger mixers are intermediaries of vertical and horizontal mixers, the incline usually being 30° (Figure 14). They are loaded from a hopper on the lower end and the material is raised by an auger fitted on the long plane of the mixer. Alternatively, they can be loaded by a pneumatic conveyor from the top. They may be fitted with more than one auger. They are emptied from the higher end and hence are easier to empty.

Figure 14: Inclined mixer showing direction of flow of materials.



Source: Simon Ndonye

Order of loading: when adding ingredients to batch mixers, 25–35% of the bulk ingredients (normally the energy concentrates) should be added first, followed by premixed ingredients, protein sources, and the rest of the bulk. Liquids, if included, should be added 70% of way through the mixing time. Premixing of small ingredients with the main ingredient helps to achieve better mixing.

Mixer type, sequencing of ingredients, length of mixing time, and ingredient particle size and density all affect mixing efficiency.

Mixers should be cleaned (flushing) out with ground grain (e.g. maize flour weighing approximately 2.5–5% the mixer capacity) after mixing medicated feed to prevent any contamination of subsequent batches. The flushing time should be approximately 5–10minutes.

Mixer testing

To ensure thoroughness of mixing, mixers need regular checking to minimize variability. A variety of methods can be used, and some are more effective than others. These include:

Physical senses such as smell, sight, and feeling for texture are the least reliable method due to their subjectivity.

Dye salts mixed uniformly within the final mix may indicate the effectiveness of the mixer and are more effective than using physical senses alone.

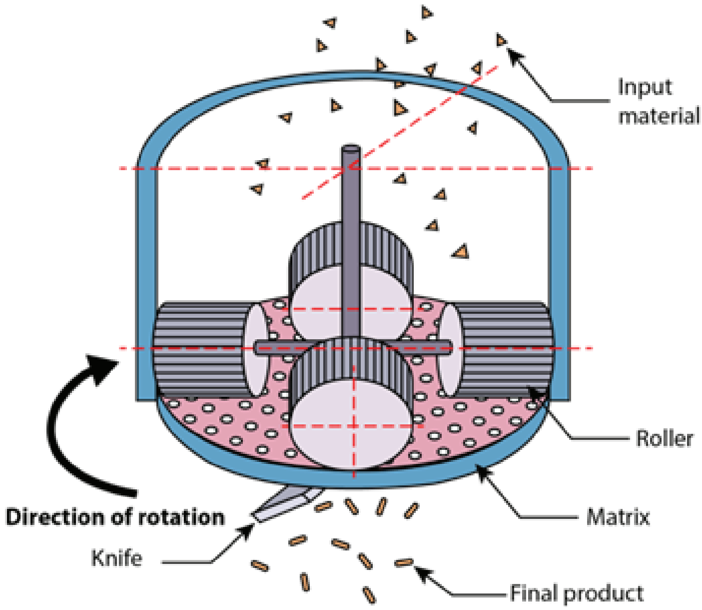
Chemical tests that sample serially at the point of mix discharge for a specific nutrient or compound are a good measure of mixing. Primary nutrients (energy and protein) are not accurate indicators. The best indicators are the micro-nutrients, which are present in such small quantities that they may disappear in one area of a mix. Sodium or chloride ions are often used for testing mixer effectiveness.

7.4.3 Pelleting

Pelleted feed is preferred by farmers for various reasons, but mostly due to ease of handling. Pelleting reduces segregation of ingredients during feeding, reduces feed losses, and improves intake. The heat generated during pelleting eliminates pathogens present in raw materials. Where post-manufacturing quality control is not possible, pelleting ensures that no adulteration of the feed occurs during distribution. The main disadvantage of pelleting is the added cost.

Pelletization is achieved by compressing mixed feed though holes (die) in a hardened steel ring using rollers (Figure 14). The die forms the feed into pencil-like extrusions which are cut by knives into pellets of desired length. The pelleting process is energy intensive, with the diameter of the feed pellets determining the power demand: the smaller the pellet, the greater the energy requirement and cost of manufacture.

Figure 15: Simplified illustration of pelleting equipment.



Source: Simon Ndonye

Pellet quality is determined by the hardness and resistance to breakage during handling. Some mixtures do not bind well when pelleted and require additional binding agents. Molasses is recommended at 1–2%. Sodium or calcium bentonite and starch are used.

7.4.4 Feed packaging

Mixed commercial animal feeds are usually packaged in bags for distribution. These bags are normally filled directly from the mixer and weighed with a scale immediately after bagging. Polythene is the most common type of bag, though compared with jute or sisal there is an increased risk of sweating and mould growth. Feeds are normally packaged in 10 kg, 20 kg, 50 kg, and 70 kg bags.

7.4.5 Quality control and standard operating procedures

Quality control along the whole manufacturing chain is essential to ensure business continuity for the manufacturer and optimal productivity at farm level. Quality control can be regulated by government bodies or through professional associations' codes of practice. Standard operating procedures exist in some countries, which must be followed by all manufacturers. These cover, but are not limited to, the following areas:

- location, siting, design and layout of the manufacturing plant
- organization of equipment, its installation, management and monitoring
- mandatory qualification and training of personnel
- hygiene of personnel and premises
- sourcing, receiving and storing of raw materials
- documentation of goods received
- packaging materials
- labelling of finished products

- transportation of finished goods
- sampling and analysis and documenting results
- customer complaint handling

The Kenyan standard is cited as KS 2543:2014: code of practice in the animal feed industry.

References

Chetrariu, A and Dabija, A. 2020. Brewer's Spent Grains: Possibilities of Valorization, a Review. *Applied Sciences* 10(16): 5619. https://doi.org/10.3390/app10165619

Grande Rice Bran Oil. 2017. *What is rice bran oil.* (Available from: https://www.grande-rbo.com/what-is-rice-bran-oil).

IndiaMART InterMESH Ltd. 2021. *Seed cake*. (Available from https://www.indiamart.com/proddetail/seed-cake-9737592012.html).

Parr, W.H. 1988. *The small-scale manufacture of compound animal feed* (ODNRI Bulletin No. 9). Working Paper. (Available from http://gala.gre.ac.uk/11051).

Patch to Table. 2021. *Best type of feed that chicken love*. (Available from: https://patchtotable.com/chickens/feed-types/).

Protinex Advanced Feed Industries [no date]. *Cotton seed meal*. (Available from https://www.exportersindia.com/protinex-advance-feed-industries/catering-services.htm#5133947).

Rice Processing. [no date]. *Rice processing technology and equipment*. (Available from https://rice-processing.com/rice-processing-technology-equipment.html).

ISBN:92–9146–657–4

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